Global Precipitation Measurement (GPM)

Ground Validation System

Level 3 Requirements

2 June 2008

DRAFT

Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

CM FOREWORD

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Questions or comments concerning this document should be addressed to:

GPM Configuration Management Office
Mail Stop
Goddard Space Flight Center
Greenbelt, Maryland 20771

Signature Page

Prepared by:

<Enter Name Here> <Enter Position Title Here> <Enter Org/Code Here>	Date

Reviewed by:

<Enter Name Here> <Enter Position Title Here> <Enter Org/Code Here>	Date	<Enter Name Here> <Enter Position Title Here> <Enter Org/Code Here>	Date

Approved by:

<Enter Name Here> <Enter Position Title Here> <Enter Org/Code Here>	Date	<Enter Name Here> <Enter Position Title Here> <Enter Org/Code Here>	Date

Concurred by:

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Global Precipitation Measurement

DOCUMENT CHANGE RECORD

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REV LEVEL	DESCRIPTION OF CHANGE	APPROVED BY	DATE APPROVED

List of TBDs/TBRs

Item No.	Location	Summary	Ind./Org.	Due Date

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1 GVS OVERVIEW

1.1 Background and Purpose

This specification defines the Level 3 functional and performance requirements for NASA's Global Precipitation Measurement (GPM) mission Ground Validation System (GVS). Overall, the GPM mission has defined a series of scientific objectives which include improvement in predicting terrestrial weather, climate, and hydrometeorology through a better observational understanding of the global water cycle. The GVS contributes to the GPM mission by providing data and observations needed for precipitation retrieval algorithm development in the pre-launch time frame, and by providing independent evaluation of precipitation products post-launch. For its part, the GVS applies three overarching approaches to validation of GPM. These approaches, defined in the *GPM GVS Science Implementation Plan* are:

- *National Networks:* Contributions of calibrated ground observations from operational and research instruments, regional and continental scale precipitation and hydrological products with associated error models, the development of downscaling models, and other related activities on large regional or continental scales;
- *Physical Process studies and field campaigns:* Contributions of targeted ground and aircraft measurements of cloud microphysical properties, precipitation, radar reflectivity, and radiances; modeling activities related to atmospheric simulation and retrieval algorithm testing; other relevant observations on local to regional scales
- *Integrated hydrometeorology applications:* Contributions related to assessment of satellite precipitation products at integrated hydrological sites using stream gauges and other hydrological measurements, formulation and application of downscaling methodologies, and analysis of the utility of satellite precipitation products for basin-scale water budget studies.

1.2 Document Scope

This document sets forth requirements for NASA's GPM GVS including necessary ground validation measurement, data ingest, processing, archiving, and distribution. The entire mission timeline is covered: from pre-launch to the end of the required GPM core and constellation satellite missions. This document *does not* include the functional and performance requirements for the GVS Ka/Ku-band mobile radar. The requirements for this radar are contained in a separate document which will be used as the basis for the radar procurement (see Section 1.5, Reference Documents).

The structure and functional breakdown of this document are used to organize the requirements only, and should not be interpreted as a physical architecture or allocation. Physical attributes and implementation approaches of the GVS are intentionally omitted from this document.

The GVS requirements presented in this document are traceable to the NASA GPM Level 2 Requirements (see Section 6).

1.3 GVS Definition

The Global Precipitation Measurement (GPM) mission is a partnership between the National Aeronautics and Space Administration (NASA) and the Japanese Aerospace Exploration Agency (JAXA). NASA's Goddard Space Flight Center (GSFC) has the lead management responsibility for GPM mission. The GPM mission definition includes the following elements:

- GPM core satellite carrying the JAXA-provided Dual-frequency Precipitation Radar (DPR) and a NASA-provided, passive GPM microwave imager (GMI)
- A GMI instrument intended for flight on a "constellation" satellite provided by a partner to be determined
- A Precipitation Processing System (PPS) to generate near-real-time precipitation products and a final time series of global precipitation measurements
- A Mission Operations System for the operation of the NASA-provided spacecraft
- A Ground Validation System (GVS), consisting of several system elements employed in the independent validation of the instruments on the GPM core satellite and the associated data products generated from them.

The high-level roles within the GPM mission, and the GVS portions of them, are illustrated in Figure 1-1.

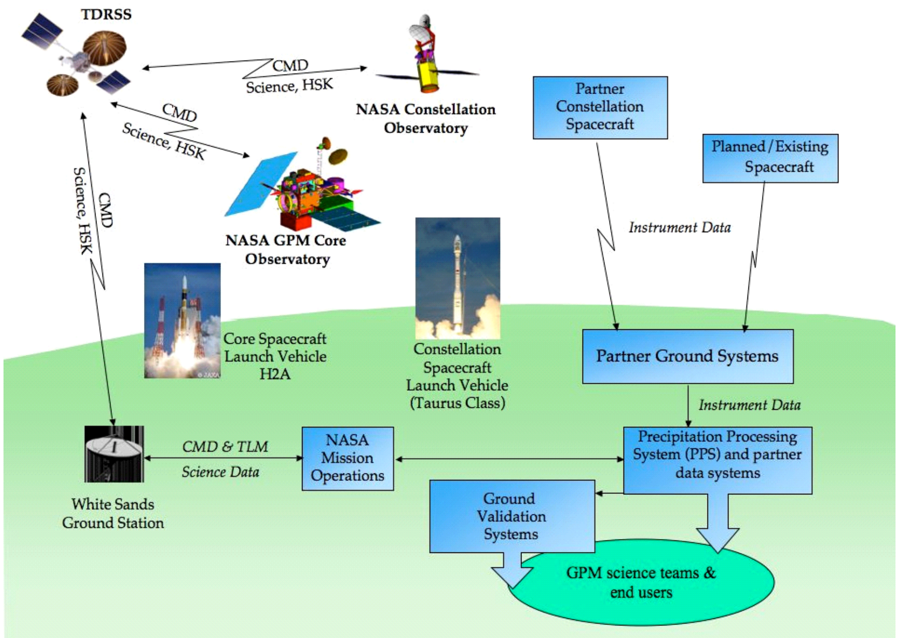

Figure 1-1 GPM Mission Architecture

In meeting its responsibilities, the GVS performs 3 main functions:

- Archive and Distribution functions collect ground validation data, products and reports, and make them available to members of the Precipitation Measuring Mission Science Team and other requestors.
- Measurement and Product Generation functions support field campaigns that collect atmospheric data and generate associated products
- Validation Network functions compare GPM satellite data and data products to similar measurements and products from the national network of operational weather radars and hydrologic measurements

The requirements associated with the main functions of the GVS are presented in Sections 2 through 4 of this document.

1.4 Applicable Documents

The following are considered the controlling documents for this specification:

- NASA GPM Project Level 1 Requirements.
- NASA Global Precipitation Measurement (GPM) Mission (L2) Requirements Document (420.2-REQS-013001A).

1.5 Reference Documents

The following documents are specifically referenced in one or more of the GVS requirements:

- Global Precipitation Measurement Ground Validation System Level 3 Requirements for a Mobile Ka-/Ku-band Radar
- PPS Level 3 Requirements.
- Federal Meteorological Handbook No. 3 (FMH-3), edition FCM-H3-1997 (<http://www.ofcm.gov/fmh3/text/default.htm>).
- DOE/SC-ARM/TR-79, Disdrometer and Tipping Bucket Rain Gauge Handbook, January 2006, M.J. Bartholomew.
- Federal Meteorological Handbook No. 3 (FMH-3), edition FCM-H3-1997 (<http://www.ofcm.gov/fmh3/text/default.htm>).
- Code Form For Temp Rawinsonde Observations in FMH-3 edition FCM-H3-1997

1.6 Document Organization

Section 1 of this document provides introduction and background information on the GVS, including an overview of the GVS and its operations. Section 2 defines the overall GVS requirements. Section 3 defines requirements for ground and aircraft-based measurements associated with GVS field campaigns. Section 4 defines the requirements for the GVS Validation Network (VN). Sections 5 through 7 respectively define acronyms and symbols used this document, provide requirements traceability, and define work-off items.

2 GVS OVERALL REQUIREMENTS

2.1.1 Ready for operations

GV43 The GVS shall be ready for operations at least 6 months prior to the projected launch of the GPM core satellite.

Rationale: Operations date specified in Level 2 requirements (MRD453).
Note: GVS operations will comply with all applicable NASA/GSFC Mission Assurance Requirements (MAR), NASA Program Requirements (NPRs) and Goddard Project Requirements (GPRs) as defined in the GPM Mission Assurance Requirements, and other applicable documents.

Verification Method: Demonstration.

2.1.2 Operations lifetime

GV48 The GVS shall operate for the minimum required lifetime of the GPM Core and Low Inclination Orbit (LIO) Satellites.

Rationale: Operations lifetime specified in Level 2 requirements (MRD445)
Verification Method: Demonstration and Analysis.

2.1.3 Secure data rights

GV52 The GVS shall secure rights for all data products, reports, documentation and computer code that it makes available for archive and distribution.

Rationale: GVS will need to secure data rights to ensure that its holdings can be freely distributed.
Verification Method: Inspection of Materials

2.1.4 Mange data policies and procedures

GV56 The GVS shall document, archive and distribute its data policies and procedures.

Rationale: GVS will need to define a data protocol, similar to that developed for Canadian CloudSat/CALIPSO Validation Programme.
Verification Method: Inspection of Materials and Interfaces

2.1.5 Conduct configuration management

GV60 The GVS shall maintain configuration control, at a minimum over

Rationale:
Internal systems and software

Data holdings, including products, reports, documentation and computer code.

Verification Method: Demonstration

3 ARCHIVE AND DISTRIBUTION (A&D) REQUIREMENTS

3.1 A&D contents

GV67 The GVS shall archive and distribute data from:
a. The GVS Validation Network (VN)
b. GVS field campaigns
c. Ancillary data sources as needed.

Rationale: A fundamental role for the GVS is maintaining and disseminating scientific data.
Verification Method: Inspection and Demonstration

3.2 A&D ingest capability

GV74 The GVS shall archive data, products, reports, documentation, and computer code.

Rationale: See GV67.
Verification Method: Inspection

3.3 A&D archive capability

GV78 The GVS shall retain all data from external sources in the original form in which it was received.

Rationale: This ensures that revised products can be generated from original data without the need to re-ingest the data from its source.
Verification Method: Inspection

3.4 A&D search and order capability

GV82 The GVS shall provide a user interface for search and order of all materials in its archive.

Rationale: A user interface is a fundamental part of an archive and distribution capability.
Verification Method: Demonstration

3.5 A&D distribution capability

GV86 The GVS shall distribute all versions of materials in its archive on request.

Rationale: See GV67.
Verification Method: Demonstration

3.6 A&D user services capability for PMM Science Team Members

GV90 The GVS shall provide off-line responses to PMM Science Team member inquiries.

Rationale: PMM Science Team Members may need help in understanding the format and content of GVS data holdings.
Verification Method: Demonstration

3.7 A&D metrics capability

GV94 The GVS shall generate metrics on its archive and distribution functions.

Rationale: Metrics provide insight into GVS operations and can be used to diagnose performance problems.
Verification Method: Inspection and Demonstration

3.8 A&D data delivery time-line

GV98 The GVS shall make data available for search and delivery within 24 hours of receipt during nominal operations.

Rationale: Data need to be cleared from the ingest queue to prevent back-logs.
Verification Method: Demonstration

3.9 A&D electronic data delivery

GV102 The GVS shall provide the capability to deliver materials in its archive electronically over the Internet in response to user requests.

Rationale: Electronic data delivery is a basic function of archive and distribution systems.
Verification Method: Demonstration

3.10 A&D long-term archive

GV106 The GVS shall, at the end of its lifecycle, make all current versions of materials in its archive available for long-term archive by an organization external to the GVS.

Rationale: Consistent with NASA policy for scientific data.
Verification Method: Inspection

3.11 Check validity of data received

GV110 The GVS shall check the validity of all data received.

Rationale: GVS needs to ensure that all ingested files contain valid data.
Verification Method: Demonstration and Inspection.

3.12 Check validity of data distributed

GV114 The GVS shall check the validity of all data distributed.

Rationale: GVS needs to ensure that all distributed files contain valid data.
Verification Method: Demonstration and Inspection.

4 FIELD MEASUREMENT AND PRODUCT GENERATION REQUIREMENTS

4.1 Overall FMPG requirements

4.1.1 Instrument Documentation

GV120 The GVS shall archive "Instrument Handbook" documentation for each instrument used in its field campaigns with, at a minimum, the following contents:

a. Instrument point of contact

b. Data description, including formats, and examples

c. Primary variables measured, derived or retrieved

d. Expected uncertainty

e. Method(s) for obtaining date/time stamps for products and measurements, including date/time stamp precision and accuracy

f. Data quality

g. Calibration and validation methods

h. Instrument metrics

i. File naming convention.

Note: It is assumed that Instrument PIs will provide this information. The DOE/ARM instrument handbooks are the model for this requirement. See, for example, DOE/SC-ARM/TR-79, D*isdrometer and Tipping Bucket Rain Gauge Handbook*, January 2006, M.J. Bartholomew.

Verification Method: Inspection of Materials

4.1.2 File date/time stamps

GV133 The GVS shall include date/time stamps in the names of all GVS data products.

Rationale: Data and data products from remote-sensing and in-situ sensors must be tagged with times of sufficient accuracy to be representative of the state of the measured element at the indicated time in the product, and to allow valid inter-comparisons between data products from other observing systems or units. Data files should include time stamps within the file naming convention which allow human or machine interpretation of the date and time of the data contained within the file, and be of sufficient granularity to support data selection and data organization.

Note: See GV120 for requirements on reporting date/time stamp accuracy and precision.

Verification Method: Inspection

4.1.3 Measurement time stamps

GV138 The GVS shall associate date/time stamps with each measurement in each GVS data product or database.

Rationale: See GV133.

Note: Date/time stamps may be associated with individual measurements explicitly or through the use of relative date/time offsets.

Verification Method: Inspection

4.1.4 Network Time Protocol (NTP) Server

GV143 The GVS shall employ a common network time protocol (NTP) server to maintain absolute clock time used by GVS instruments in applying date/time stamps.

Rationale: NTP servers are considered a "best practice" for obtaining date/time stamps in field campaigns and similar activities. NTP servers are expected to be used in maintaining a common time reference for many instruments during GVS filed campaigns.

Verification Method: Demonstration

4.2 Product Generation Requirements

4.2.1 Derived Products: products that are interpolated in time or space and/or are based on additional assumptions

4.2.1.1 X-band scanning radar product Cartesian grid

GV149 The GVS shall generate X-band radar products (defined below) interpolated from polar coordinates to a 3-dimensional Cartesian grid with, at a minimum, the following characteristics:

a. Cartesian grid center located at the X-band scanning radar

b. Cartesian grid extending 30 km in the X,Y (east-west, north-south) direction from the location of the radar

c. Cartesian grid extending in the Z (vertical) direction from 0.5-18 km above ground level

d. Resolution of the Cartesian grid in all dimensions not to exceed the actual radar beam resolution at maximum horizontal range.

Rationale: X-band radar components need to be mapped to a Cartesian grid, since the original polar-coordinate product data are incompatible with requirements for use of the data. The 3-D Cartesian gridded data will be used as input to Satellite Simulation Models (SSM), for validation of Cloud Resolving Models (CRM), and to evaluate the calibration and attenuation correction of the satellite-borne PR/DPR. The domain and resolution of the 3-D grid are driven by the X-band radar characteristics, sampling theory, and product usage.

Verification Method: Inspection and Analysis

4.2.1.2 S-band scanning radar product Cartesian grid

GV157 The GVS shall generate S-band radar products (defined below) interpolated from polar coordinates to a 3-dimensional Cartesian grid with, at a minimum, the following characteristics:
a. Cartesian grid center located at the X-band scanning radar
b. Cartesian grid extending 60 km in the X,Y (east-west, north-south) direction from the location of the radar
c. Cartesian grid extending in the Z (vertical) direction from 0.5-18 km above ground level
d. Resolution of the Cartesian grid in all dimensions not to exceed the actual radar beam resolution at maximum horizontal range.

Rationale: As for GV149, but for S-band radar.
Verification Method: Inspection and Analysis

4.2.1.3 X-band re-sampled equivalent reflectivity factor product

GV165 The GVS X-band scanning radar shall generate a resampled horizontal and vertical equivalent reflectivity factor (rZh and rZv in dB) product resampled to the Cartesian grid defined in Requirement GV149 for each PPI-volume scan of radar data.

Rationale: See GV149. Primarily, X-band reflectivity will be compared to satellite radar reflectivity on a common grid to validate the calibration of each instrument and the effectiveness of the PR/DPR attenuation corrections. It will also be used in computation of rain rates using the traditional Z-R as well as polarimetric relationships. 2 dB is the minimum accuracy required for these purposes.
Note: The goal for the rZh and rZv product is an accuracy of 2.0 dB or better for any grid element in the entire resampled radar scan volume.

Verification Method: Inspection

4.2.1.4 X-band re-sampled differential reflectivity product

GV170 The GVS X-band scanning radar shall generate a resampled differential reflectivity factor (rZdr in dB) product resampled to the Cartesian grid defined in Requirement GV149 for each PPI-volume scan of radar data.

Rationale: See GV149. Differential reflectivity is needed to estimate Drop Size Distributions, detect the presence of hail, and estimate rainfall using polarimetric parameters.
Note: The goal for the rZdr product is an accuracy of 0.4 dB or better for any grid element in the entire resampled radar scan volume.

Verification Method: Inspection

4.2.1.5 X-band scanning radar specific differential phase product

GV175 The GVS X-band scanning radar shall generate a differential phase (Kdp in degrees/km) product re-sampled to the Cartesian grid specified in requirement GV149.

Rationale: See GV149. Differential phase is needed to estimate rainfall intensity and accumulation, especially in the presence of hail. It is highly immune to radar calibration errors and partial beam blockage.
Note: The goal for the Kdp product is an accuracy of 0.3 degrees/km or better over a minimum distance of 3 km for any measurement in the entire radar scan volume where reliable differential propagation phase measurements can be obtained

Verification Method: Inspection

4.2.1.6 S-band re-sampled equivalent reflectivity factor product

GV180 The GVS S-band scanning radar shall generate a resampled horizontal and vertical equivalent reflectivity factor (rZh and rZv in dB) product resampled to the Cartesian grid defined in Requirement GV157 for each PPI-volume scan of radar data.

Rationale: See GV165
Note: The goal for the rZh and rZv product is an accuracy of ≤2.0 dB for any grid element in the entire resampled radar scan volume.

Verification Method: Inspection

4.2.1.7 S-band re-sampled differential reflectivity product

GV185 The GVS S-band scanning radar shall generate a resampled differential reflectivity factor (rZdr in dB)) product resampled to the Cartesian grid defined in Requirement GV157 for each PPI-volume scan of radar data.

Rationale: See GV170.
Note: The goal for the rZdr product is an accuracy of ≤0.4 dB for any grid element in the entire radar scan volume.

Verification Method: Inspection

4.2.1.8 S-band scanning radar specific differential phase product

GV190 The GVS S-band scanning radar shall generate a specific differential phase (Kdp in degrees/km) data product re-sampled to the Cartesian grid specified in requirement GV157.

Rationale: See GV67.
Note: The goal for the Kdp product is an accuracy of ≤0.3 degrees/km over a minimum distance of 3 km for any measurement in the entire radar scan volume where reliable differential propagation phase measurements can be obtained

Verification Method: Inspection

4.2.1.9 Scanning radar liquid water content product

GV195 The GVS shall generate a vertical profile of atmospheric liquid water content product (in g/m3) sampled to a 3-dimensional grid with a horizontal resolution not to exceed the actual radar beam resolution for each PPI-volume scan of radar data.

Rationale: Vertical profiles of atmospheric liquid water are needed as input to and validation of SSMs, and for validation and initiation of Cloud-system Resolving Models (CRMs). These data will supplement moisture profiles collected by upper air soundings. Accuracies are based on the instrument measurement requirements. Temporal resolution is the minimum required to provide a representative measurement in changing atmospheric conditions.
Verification Method: Inspection and Analysis

4.2.1.10 Scanning radar hydrometeor identification product

GV199 The GVS shall generate a hydrometeor type product with, at a minimum, the following characteristics:
a. The hydrometeor type product generates estimates of the most likely hydrometeor types sampled to a 3-dimensional grid with a horizontal resolution not to exceed the actual radar beam resolution for each PPI-volume scan of radar data
b. The hydrometeor type product classifies hydrometeors into at least the following types: light rain, moderate rain, heavy rain, rain mixed with precipitation-sized ice, and precipitation-sized ice only (warm season) and low density snow, high density snow, and mixed precipitation (cold season).

Rationale: Knowledge of actual hydrometeor types is needed to model and validate microwave precipitation retrievals and CRM microphysics, and improve active radar attenuation algorithms.
Verification Method: Inspection and Analysis

4.2.1.11 Scanning radar median drop diameter product

GV205 The GVS shall generate a median drop diameter D0 product (in mm) sampled to a 3-dimensional grid with a horizontal resolution not to exceed the actual radar beam resolution for each PPI-volume scan of radar data.

Rationale: See GV170 and GV185 GV205, GV210, and GV215 are related and interdependent. D0 in combination with number concentration of liquid droplets (GV215) is needed to make accurate determination of rain rates from radar and to compute attenuation estimates.
Note: The goal for the D0 product is an accuracy of ≤0.2 mm.

Verification Method: Inspection and Analysis

4.2.1.12 Scanning radar instantaneous rain rate product

GV210 The GVS shall generate a rain intensity product (in mm/hr) sampled to a 3-dimensional grid with a horizontal resolution not to exceed the actual radar beam resolution for each PPI-volume scan of radar data

Rationale: See GV205. Rain rate is the primary measured element to be validated in GPM. Rain rate estimates from scanning radar will be one of the validating measurements.
Note: The goal for the rain intensity product is an accuracy of ±20%.

Verification Method: Inspection and Analysis

4.2.1.13 Scanning radar number concentration - liquid product

GV215 The GVS shall generate a drop number concentration product that estimates of the number of liquid water drops per volume (in m-3) sampled to a 3-dimensional grid with a horizontal resolution not to exceed the actual radar beam resolution for each PPI-volume scan of radar data

Rationale: See GV205.
Verification Method: Inspection and Analysis

4.2.1.14 S and UHF band profiler pair median particle diameter product

GV219 The GVS shall generate a vertical profile of median particle diameter product (in mm) with, at a minimum, the following characteristics:
a. product height resolution of ≤62.5 m, starting at 200 m above ground level (AGL) and extending to 18 km AGL.
b. product profiles generated from all available profiler data where reliable estimates can be derived.

Rationale: The raindrop size distribution can be described by a Gamma function with three parameters: median particle diameter (GV219), particle concentration (GV226), and Gamma shape parameter (GV233). Using the assumed Gamma function, the DSD can be retrieved from the profiler pair data. Profiler DSD estimates also provide an independent measurement directly comparable to GV205, with a greater height resolution to match with PR and DPR measurements. A 62.5 m pulse length is a typical value for this class of profilers. See GV481 and GV549 for height rationales.
Note: The goal for profiler height resolution is 30 m.

Verification Method: Inspection

4.2.1.15 S and UHF band profiler pair particle concentration product

GV226 The GVS shall generate a vertical profile of particle concentration product (in m-3) with, at a minimum, the following characteristics:
a. product height resolution of ≤62.5 m, starting at 200 m AGL and extending to 18 km AGL.
b. product generated from all available profiler data where reliable estimates can be derived.

Rationale: The raindrop size distribution can be described by a Gamma function with three parameters: median particle diameter (GV219), particle concentration (GV226), and Gamma shape parameter (GV233). Using the assumed Gamma function, the DSD can be retrieved from the profiler pair data. Profiler DSD estimates also provide an independent measurement directly comparable to GV215, with a greater height resolution necessary to match with PR and DPR measurements. A 62.5 m pulse length is a typical value for this class of profilers.
Note: The goal for profiler height resolution is 30 m.

Verification Method: Inspection and Analysis

4.2.1.16 S and UHF band profiler pair shape parameter product

GV233 The GVS shall generate a vertical profile of a Gamma shape parameter product (unitless) with, at a minimum, the following characteristics:
a. a product vertical resolution of ≤62.5 m, starting at 200 m and extending to 18 km
b. product generated from all available profiler data where reliable estimates can be derived.

Rationale: The raindrop size distribution can be described by a Gamma function with three parameters: median particle diameter (GV219), particle concentration (GV226), and Gamma shape parameter (GV233). Using the assumed Gamma function, the DSD can be retrieved from the profiler pair data. Profiler DSD estimates also can help validate precipitation type estimates from scanning radar (GV210), as well as from PR/DPR. The vertical resolution, starting and ending heights are the same as those used in GV219 and GV226.
Note: The goal for the vertical resolution is 30 m.

Verification Method: Inspection and Analysis

4.2.1.17 S and UHF band profiler pair vertical air motion product

GV240 The GVS shall generate a vertical profile of vertical air motion product (in units m/s) with, at a minimum, the following characteristics:
a. product vertical resolution of ≤62.5 m, starting at 200 m AGL and extending to 18 km AGL.
b. product generated from all available profiler data where reliable estimates can be derived.

Rationale: The rain rate is the mass flux of water passing a reference plane, and the air motion increases or decreases the total mass flux. Air motion can also be used for validation of CRM simulations. A 62.5 m pulse length is a typical value for this class of profilers. See GV481 and GV549 for height rationales.
Verification Method: Inspection and Analysis

4.2.1.18 Disdrometer particle diameter product

GV246 The GVS shall generate a median particle diameter product (in mm) with a temporal resolution of ≤1 minute.

Rationale: Disdrometer median particle diameter estimates are needed to provide ground truth measurements for GV205 and GV219 and to determine the validity of the Z-R relationships for the active radars. 1-minute intervals are common practice in the literature and in operations, e.g., Disdrometer and Tipping Bucket Rain Gauge Handbook, January 2006, DOE/SC-ARM/TR-079. Bringi also uses 1-minute averages, see http://gpm.gsfc.nasa.gov/images/CARE_2DVD_6Dec2006.pdf
Verification Method: Inspection

4.2.1.19 Disdrometer number concentration product

GV250 The GVS shall generate a particle concentration product (in number of drops/m3) with a temporal resolution of ≤1 minute.

Rationale: As in GV246, but for particle number concentrations (GV215 and GV226).
Verification Method: Inspection

4.2.1.20 Disdrometer rain rate product

GV254 The GVS shall generate a precipitation rate product (in mm/hr) with a temporal resolution of ≤1 minute.

Rationale: As in GV246. Needed to provide ground truth for GV210.
Verification Method: Inspection

4.2.1.21 Disdrometer radar reflectivity product

GV258 The GVS shall generate a radar reflectivity product (in dBZ) with a temporal resolution of ≤1 minute.

Rationale: Provides ground truth for GV165, GV170 and GV205. Requires GV246 and GV250 as inputs.
Verification Method: Inspection

4.2.1.22 Rain gauge rain rate product

GV262 The GVS shall generate a rain gauge precipitation rate product (in mm/hr) with a temporal resolution of ≤1 minute.

Rationale: Rain gauge rain rate is needed to validate the remotely-sensed (GV210) and in-situ derived (GV254) rain rate estimates, as well as those from the TMI/GMI and PR/DPR.
Verification Method: Inspection

4.2.1.23 Profiling microwave radiometer temperature profiles product

GV266 The GVS shall generate a product consisting of vertical profiles of temperature (in K) with, at a minimum, the following characteristics:
a. The vertical profile of temperature product has a vertical resolution of ≤1 km, starting at ground level to 10km AGL
b. The vertical profile of temperature product has temporal resolution of 5 minutes.

Rationale: CRM validation and a supplement to temperature profiles provided by upper air soundings.
Note: Spatial and temporal resolution requirements are based on the 12-channel Microwave Radiometer Profiler as described in the DOE ARM Microwave Radiometer Profiler Handbook, and in communication with the ARM/SGP "Instrument Mentor." The vertical resolution varies from 500m at lower altitudes to 1 km at higher altitudes.
Verification Method: Inspection

4.2.1.24 Profiling microwave radiometer water vapor concentration profiles product

GV273 The GVS shall generate a product consisting of vertical profiles of water vapor concentration (in g/m3) with, at a minimum, the following characteristics:
a. The vertical profile of water vapor concentration product has a vertical resolution of ≤1 km, starting at ground level to 10 km AGL
b. The vertical profile of water vapor concentration product has a temporal resolution of 5 minutes.

Rationale: CRM validation and a supplement to temperature profiles provided by upper air soundings.
Verification Method: Inspection

4.2.2 Measured Products: products generated in the native coordinates of the instrument with no interpolation in time or space

4.2.2.1 X-band scanning radar equivalent reflectivity factor product

GV280 The GVS X-band scanning radar shall generate a calibrated horizontal and vertical equivalent reflectivity factor (Zh and Zv) product (in dB).

Rationale: An accuracy of 1.0 dBZ is necessary to provide sufficient accuracy of the rain rate derived from reflectivity, and to match the reflectivity accuracy requirements of the GPM DPR.
Note: The goal of the Zh and Zv product is an accuracy of ≤1.0 dB for measurements at all ranges and elevations, independent of any attenuation correction.
Verification Method: Inspection

4.2.2.2 X-band scanning radar differential reflectivity product

GV285 The GVS X-band scanning radar shall generate a calibrated differential reflectivity (Zdr) product (in dB).

Rationale: As in GV170, but in the native range, azimuth coordinates of the radar.
Note: The goal of the Zdr is an accuracy ≤ 0.2 dB independent of any attenuation correction.
Verification Method: Inspection

4.2.2.3 X-band scanning radar differential propagation phase product

GV290 The GVS X-band scanning radar shall generate a differential propagation phase (_dp in degrees) product.

Rationale: As in GV67, but in the native range, azimuth coordinates of the radar. Differential propagation is also used to eliminate ground clutter from the scan.
Note: The goal of the _dp product is an accuracy of ≤3.0 degrees for any measurement in the entire radar scan volume where the radar signal has not been completely attenuated.

Verification Method: Inspection

4.2.2.4 X-band scanning radar co-polar correlation coefficient product

GV295 The GVS X-band scanning radar shall generate a correlation coefficient product (unitless) of the horizontal and vertical return signal (_hv).

Rationale: The correlation coefficient is needed in concert with other measured and derived parameters to help distinguish between precipitation types and to help eliminate ground clutter.
Note: The goal of the co-polar correlation coefficient product is with an accuracy of ≤0.005 for any measurement in the entire radar scan volume.

Verification Method: Inspection

4.2.2.5 X-band scanning radar linear depolarization ratio product (optional)

GV300 The GVS X-band scanning radar shall generate a linear depolarization ratio (LDR) product (in dB).

Rationale:
Note: The goal of the LDR product is an accuracy of ≤1.0 dB (when averaged over distances of 1 km) for both horizontal transmit/vertical receive and vertical transmit/horizontal receive conditions for any measurement in the entire radar scan volume.

Note: the default mode of data collection for the GVS X-band scanning radar will be simultaneous transmission and simultaneous reception (STSR) and depolarization information will not be collected. As required, the GVS X-band scanning radar will operate in a mode capable of measuring the depolarization ratio (e.g., simultaneous transmit alternate reception - STAR mode).

Verification Method: Inspection

4.2.2.6 X-band scanning radar Doppler radial velocity product

GV306 The GVS X-band scanning radar shall generate a Doppler radial velocity product (in m/sec).

Rationale: Single or multiple Doppler wind retrievals will be used to validate CRM kinematic structure.
Note: The goal of the Doppler radial velocity product is an accuracy of +/- 1 m/sec for any measurement in the entire radar scan volume.

Verification Method: Inspection

4.2.2.7 S-band scanning radar equivalent reflectivity factor product

GV311 The GVS S-band scanning radar shall generate a horizontal and vertical equivalent reflectivity factor (Zh and Zv) product (in dB).

Rationale: See GV280.
Note: The goal for the Zh and Zv product is an accuracy of ≤1.0 dB for any measurement in the entire radar scan volume, independent of any attenuation correction.

Verification Method: Inspection

4.2.2.8 S-band scanning radar differential reflectivity product

GV316 The GVS S-band scanning radar shall measure differential reflectivity factor (Zdr) product (in dB).

Rationale: As in GV285, but for S-band radar.
Note: The goal of the Zdr product is an accuracy of ≤0.2 dB for any measurement in the entire radar scan volume, independent of any attenuation correction.

Verification Method: Inspection

4.2.2.9 S-band scanning radar differential propagation phase product

GV321 The GVS S-band scanning radar shall measure differential propagation phase (_dp in degrees) product.

Rationale: As in GV290, but for S-band radar.
Note: The goal of the _dp product is an accuracy of ≤3.0 degrees for any measurement in the entire radar scan volume where the radar signal has not been completely attenuated.

Verification Method: Inspection

4.2.2.10 S-band scanning radar horizontal-vertical correlation coefficient product

GV326 The GVS S-band scanning radar shall generate a correlation coefficient product (unitless) of the horizontal and vertical return signal (_hv) for periods of arbitrary length.

Rationale: As in GV295, but for S-band radar.
Note: The goal of the _hv product is an accuracy of ≤0.005 for any measurement in the entire radar scan volume.

Verification Method: Inspection

4.2.2.11 S-band scanning radar linear depolarization ratio product (optional)

GV331 The GVS S-band scanning radar shall generate a linear depolarization ratio (LDR) product (in dB).

Rationale: LDR is a good indicator of regions where a mixture of precipitation types occur and can be used as a hydrometeor identification discriminator.
Note: The goal of the LDR product is an accuracy of ≤1.0 dB (when averaged over distances of 1 km) for both horizontal transmit/vertical receive and vertical

transmit/horizontal receive conditions for any measurement in the entire radar scan volume.

Note: the default mode of data collection for the GVS S-band scanning radar will be simultaneous transmission and simultaneous reception (STSR) and depolarization information will not be collected. As required, the GVS S-band scanning radar will operate in a mode capable of measuring the depolarization ratio (e.g., simultaneous transmit alternate reception - STAR mode).

Verification Method: Inspection

4.2.2.12 S-band scanning radar Doppler radial velocity product

GV337 The GVS S-band scanning radar shall generate a Doppler radial velocity product (in m/sec).

Rationale: Single or multiple Doppler wind retrievals will be used to validate CRM kinematic structure.
Note: The goal of the Doppler radial velocity product is an accuracy of +/- 1 m/sec for any measurement in the entire radar scan volume.

Verification Method: Inspection

4.2.2.13 S-band profiler Doppler spectra product

GV342 The GVS S-band profiler shall generate a Doppler spectra product consisting of relative received power at each Doppler velocity bin.

Rationale: The spectral moments are used for identifying the freezing level and bright band heights.
Verification Method: Inspection

4.2.2.14 S-band profiler spectral moments product

GV346 The GVS S-band profiler shall generate a spectral moments product consisting of the mean reflectivity, mean reflectivity-weighted Doppler velocity, and velocity variance at each radar range gate.

Rationale: The spectral moments are used for identifying the freezing level and bright band heights.
Verification Method: Inspection

4.2.2.15 UHF profiler Doppler spectra product

GV350 The GVS UHF profiler shall generate a Doppler spectra product consisting of relative received power at each Doppler velocity bin.

Rationale: The spectral product is used for identifying the freezing level and bright band heights.
Verification Method: Inspection

4.2.2.16 UHF profiler precipitation spectral moments product

GV354 The GVS UHF profiler shall generate a spectral moments product consisting of the mean reflectivity, mean reflectivity-weighted Doppler velocity, and velocity variance at each radar range gate.

Rationale: The three velocity parameters are needed to generate the vertical air motion product (see GV358).
Verification Method: Inspection

4.2.2.17 UHF profiler vertical air motion product

GV358 The GVS UHF profiler shall generate an air motion product consisting of a Gaussian shaped function defined with the three parameters of amplitude, mean air motion velocity, and velocity variance at each radar range gate.

Rationale: Vertical air motion from the UHF profiler helps discriminate precipitation type, identify the bright band location, and improve rain rate estimation.
Verification Method: Inspection and Analysis

4.3 Instrument Measurement Requirements: X-band scanning radar

4.3.1 X-band scanning radar center frequency

GV363 The GVS X-band scanning radar shall have a center frequency of in the range of 8-12 GHz.

Rationale: 8-12 GHz spans the nominal center frequency range for an X-band radar.
Verification Method: Documentation

4.3.2 X-band scanning radar minimum and maximum elevation

GV367 The GVS X-band scanning radar shall have a range of elevation look angles from -0.5° to 90°.

Rationale: The stated elevation range is required for the X-band radar to scan, as near as practical, a full 3-D volume to meet requirement GV149.
Verification Method: Demonstration

4.3.3 X-band scanning radar minimum and maximum range

GV371 The GVS X-band scanning radar shall have a minimum operational range of ≤0.5 km and a maximum operational range of ≥75 km.

Rationale: The stated ranges are required for the X-band radar to scan, as near as practical, a full 3-D volume to meet requirement GV149, and a hydrologic basin of sufficient size for GPM GV purposes.
Verification Method: Demonstration

4.3.4 X-band scanning radar elevation pointing accuracy

GV375 The GVS X-band scanning radar shall have an elevation pointing accuracy of ≤0.2 degrees.

Rationale: This is a nominal elevation pointing accuracy for a research quality scanning radar. It maintains a beam height error upper limit of ~250m at maximum range, which is the height resolution of the DPR.
Verification Method: Testing

4.3.5 X-band scanning radar elevation pointing uncertainty

GV379 The GVS X-band scanning radar shall have an elevation pointing uncertainty of <0.1 degree.

Rationale: See GV375.
Verification Method: Testing

4.3.6 X-band scanning radar azimuth pointing accuracy

GV383 The GVS X-band scanning radar shall have an azimuth pointing accuracy of ≤0.2 degrees.

Rationale: This is a nominal azimuthal pointing accuracy for a research quality scanning radar. It maintains a beam center error upper limit of ~250m at maximum range.
Verification Method: Testing

4.3.7 X-band scanning radar azimuth pointing uncertainty

GV387 The GVS X-band scanning radar shall have an azimuth pointing uncertainty of <0.1 degree.

Rationale: See GV383.
Verification Method: Testing

4.3.8 X-band scanning radar range resolution

GV391 The GVS X-band scanning radar shall have a minimum range resolution of £50 m for all gates within the minimum and maximum range.

Rationale: The radar data must have sufficient resolution to provide meaningful information on the spatial variability of rainfall and other products.
Verification Method: Demonstration

4.3.9 X-band scanning radar horizontal/vertical resolution

GV395 The GVS X-band scanning radar shall have a half-power beam width of ≤1 degree.

Rationale: This is a nominal beam width for a research quality scanning radar.
Verification Method: Testing

4.3.10 X-band scanning radar calibration stability

GV399 The GVS X-band scanning radar shall maintain a Zh calibration within +/-2 dB.

Rationale: The GVS will have limited support for recalibration of field instrumentation, and precipitation events will occur at random, so the X-band radar needs stable calibration precision. 2 dBZ is the maximum allowable drift to give meaningful reflectivity intercomparisons with PR/DPR and compute rain rates from the ground radar.
Verification Method: Testing and analysis

4.3.11 X-band scanning radar scan rates

GV403 The GVS X-band scanning radar shall provide an azimuthal (elevation) scan rate of ≥36° (4°) sec-1.

Rationale: These rates allow the X-band radar to be scan-synchronized with the S-band radar (or any WSR-88D unit).
Verification Method: Demonstration

4.3.12 X-band scanning radar full volume scan time

GV407 The GVS X-band scanning radar shall be capable of completing a full volume scan within 12 minutes.

Rationale: Cloud characteristics and locations change rapidly enough that it is necessary to complete a volume scan within 12 minutes or less in order to make a valid comparison to the DPR/GMI observations, which are akin to a random snapshot view.
Note: A full volume scan is defined as a sequence ≥ 2 full azimuth (360°) scans, with each azimuth scan taken at a different elevation between 0° and 90° of elevation.

Verification Method: Demonstration

4.3.13 Communications

GV412 The GVS X-band scanning radar shall generate quick-look images at least every 15 minutes and these images will be available to other computers in the local network.

Rationale: An image display generation capability is necessary to locally and remotely monitor the instrument data quality and for weather situational awareness in GV field operations.
Note: These images will show low-level Plan Position Indicators (PPIs) of radar reflectivity, differential reflectivity, and specific differential phase.

Verification Method: Demonstration

4.4 Instrument Measurement Requirements: S-band scanning radar

4.4.1 S-band scanning radar center frequency

GV418 The GVS S-band scanning radar shall have a center frequency of in the range of 2.7 GHz to 2.9 GHz.

Rationale: 2.7-2.9 GHz spans the nominal center frequency range for an S-band radar and the exact frequency must be selected to not interfere with the WSR-88D network

radars, assuming the GVS S-band radar itself is not one or more of the WSR-88D systems.
Verification Method: Documentation

4.4.2 S-band scanning radar minimum and maximum range

GV422 The GVS S-band scanning radar shall have a minimum operational range of ≤1 km and a maximum operational range of ≥150 km.

Rationale: The stated ranges are required for the S-band radar to scan, as near as practical, a full 3-D volume to meet requirement GV157, and a hydrologic basin of sufficient size for GPM GV purposes.
Verification Method: Demonstration

4.4.3 S-band scanning radar minimum and maximum elevation

GV426 The GVS S-band scanning radar shall have a range of elevation look angles from -0.5° to 90°.

Rationale: The stated elevation range is required for the S-band radar to scan, as near as practical, a full 3-D volume to meet requirement GV157.
Verification Method: Demonstration

4.4.4 S-band scanning radar range resolution

GV430 The GVS S-band scanning radar shall have a range resolution of ≤75 m for all gates within the minimum and maximum range.

Rationale: The radar data must have sufficient resolution to provide meaningful information on the spatial variability of rainfall and other products.
Verification Method: Demonstration

4.4.5 S-band scanning radar horizontal/vertical resolution

GV434 The GVS S-band scanning radar shall have a half-power beam width of ≤1 degree.

Rationale: This is a nominal beam width for a research quality scanning weather radar and matches the NEXRAD specification.
Verification Method: Testing

4.4.6 S-band scanning radar azimuth pointing accuracy

GV438 The GVS S-band scanning radar shall have an azimuth pointing accuracy of ≤0.2 degrees.

Rationale: This is a nominal azimuthal pointing accuracy for a research quality scanning radar. It maintains a beam center error upper limit of ~500 m at maximum range.
Verification Method: Testing

4.4.7 S-band scanning radar azimuth pointing uncertainty

GV442 The GVS S-band scanning radar shall have an azimuth pointing uncertainty of <0.1 degree.

Rationale: See GV387.
Verification Method: Testing

4.4.8 S-band scanning radar elevation pointing accuracy

GV446 The GVS S-band scanning radar shall have an elevation pointing accuracy of ≤0.2 degrees.

Rationale: This is a nominal elevation pointing accuracy for a research quality scanning radar. It maintains a beam height error upper limit of ~500 m at maximum range.
Verification Method: Testing

4.4.9 S-band scanning radar elevation pointing uncertainty

GV450 The GVS S-band scanning radar shall have an elevation pointing uncertainty of <0.1 degree.

Rationale: See GV379.
Verification Method: Testing

4.4.10 S-band scanning radar calibration stability

GV454 The GVS S-band scanning radar shall maintain a Zh calibration within 2 dB.

Rationale: See GV399.
Verification Method: Testing and analysis

4.4.11 S-band scanning radar full volume scan time

GV458 The GVS S-band scanning radar shall be capable of completing a full volume scan within 12 minutes.

Rationale: See GV407.
Note: A full volume scan is defined as a sequence ≥ 2 full azimuth (360°) scans, with each azimuth scan taken at a different elevation between 0° and 90° of elevation.

Verification Method: Demonstration

4.4.12 S-band scanning radar scan rates

GV463 The GVS S-band scanning radar shall provide an azimuthal (elevation) scan rate of ≥36° (4°) sec-1.

Rationale: These rates allow the X-band radar to be scan-synchronized with the X-band radar (or any WSR-88D unit).
Verification Method: Demonstration

4.4.13 Communications

GV467 The GVS S-band scanning radar shall generate quick-look images at least every 15 minutes and these images will be available to other computers in the local network.

Rationale: An image display generation capability is necessary to locally and remotely monitor the instrument data quality and for weather situational awareness in GV field operations.
Note: These images will show low-level PPIs of radar reflectivity, differential reflectivity, and specific differential phase.

Verification Method: Demonstration

4.5 Instrument Measurement Requirements: S-Band Profiler

4.5.1 S-band profiler center frequency

GV473 The GVS S-band profiler shall operate at a fixed frequency in the 2700-2900 MHz radar band.

Rationale: 2700-2900 MHz spans the nominal center frequency range for an S-band radar and a fixed frequency must be selected to not interfere with the GVS S-band scanning radar or the WSR-88D network radars.
Verification Method: Documentation

4.5.2 S-band profiler bandwidth

GV477 The GVS S-band profiler shall have a signal bandwidth matched to the transmitted pulse length.

Rationale: The returned power will vary with the transmitted pulse length and the bandwidth must be able to accommodate the dynamic range of the signal.
Verification Method: Testing and Analysis

4.5.3 S-band profiler minimum and maximum range

GV481 The GVS S-band profiler shall measure at least 50 dBZ without saturating at a minimum range of 200 meters above the ground. The GVS S-band profiler shall collect observations up to 18 km above the ground.

Rationale: The GPM DPR will provide data coverage from the surface up to 18 km above ground, at 250m height resolution, with a 70 dB range. The S-band profiler must provide matching coverage within reasonable attenuation limits.
Verification Method: Demonstration

4.5.4 S-band profiler antenna (beamwidth)

GV485 The GVS S-band profiler shall have a fixed, vertically pointing antenna with a maximum half-power beamwidth of 2.5 degrees.

Rationale: 2.5 degrees is a nominal half-power beam width for an S-band profiler. It provides a spatial resolution of less than 1 km at maximum vertical range, which allows sub-bin comparisons with the X-band and S-band scanning radars and the DPR.
Verification Method: Testing and demonstration

4.5.5 S-band profiler antenna shroud

GV489 The GVS S-band profiler shall have an antenna shroud.

Rationale: An antenna shroud is needed to get the maximum performance and data quality from the profiler and gain flexibility in instrument location.
Note: An antenna shroud greatly reduces the low-angle sidelobes of the antenna.

Verification Method: Testing and Inspection

4.5.6 S-band profiler vertical resolution

GV494 The GVS S-band profiler shall have a minimum vertical resolution of 62 m.

Rationale: This resolution allows for good matching with the 125 meter resolution of the GPM DPR at nadir.
Verification Method: Testing

4.5.7 S-band profiler minimum reflectivity sensitivity (dBZ)

GV498 The GVS S-band profiler shall measure a minimum return of ≤10 dBZ at a range of 10 km.

Rationale: 10 dBZ sensitivity places the S-band profiler below the minimum reflectivity threshold of the PR and DPR.
Verification Method: Testing

4.5.8 S-band profiler calibration stability

GV502 The GVS S-band profiler shall maintain a stable reflectivity accuracy of less than 1 dBZ.

Rationale: The GVS will have limited support for recalibration of field instrumentation, and precipitation events will occur at random, so the S-band profiling radar needs stable calibration precision. 1 dBZ matches the reflectivity calibration requirement for the PR/DPR.
Note: A Joss-Waldvogel Disdrometer (JWD), or its equivalent, will be provided as part of the S-Band profiler equipment to monitor calibration of the profiler. The JWD disdrometer data will be available for other uses, but its primary purpose will be to provide calibration information for the profiler.

Verification Method: Testing and analysis

4.5.9 S-band profiler unambiguous range

GV507 The GVS S-band profiler shall have a maximum unambiguous range greater than 18 km.

Rationale: The profiler should match the GPM DPR, which measures up to 18 km in altitude.
Verification Method: Testing and analysis

4.5.10 S-band profiler dwell time

GV511 The GVS S-band profiler shall dwell for less than 15 seconds.

Rationale: A complete profile of Doppler spectra and spectral moments will be recorded for each dwell period. These Doppler spectra are used to estimate the Gamma function DSD specified in requirements GV331 through GV346.
Verification Method: Testing and analysis

4.5.11 S-band profiler Nyquist Doppler velocity and spectral resolution

GV515 The GVS S-band profiler shall have a minimum Nyquist velocity ≥16 ms-1 and a maximum Doppler spectral resolution (Doppler velocity bin spacing) ≤0.15 ms-1.

Rationale: An unambiguous velocity of 16 ms-1 allows fall speeds of all snow and rain, and of hail of up to 20 mm, to be measured in free air.
Verification Method: Testing and analysis

4.5.12 S-band profiler access to spectra for real time analysis

GV519 The GVS S-band profiler shall make the observed Doppler velocity spectra available for analysis within 15 minutes of the observation.

Rationale: A near-real-time product generation capability is necessary to locally and remotely monitor the instrument data quality and for weather situational awareness in GV field operations.
Verification Method: Demonstration

4.5.13 S-band profiler local archive

GV523 The GVS S-band profiler shall have a local storage capacity with a minimum capacity sufficient to store 30 days of continuous data.

Rationale: The GVS will not be staffed on a 24/7 schedule, and precipitation events will occur at random, so the S-band profiler system must provide its own data collection and storage mechanisms to assure data continuity.
Verification Method: Inspection

4.5.14 S-band profiler back-up archive

GV527 The GVS S-band profiler shall maintain a back-up copy of all data collected and generated.

Rationale: A local back-up of the profiler data ensures that any loss of data during transportation for off-site archival and analysis would not be catastrophic. Automatic copying of the data from the radar processor to the renewable storage devices will be part of the software.

Verification Method: Inspection

4.5.15 S-band profiler quick-look image product

GV531 The GVS S-band profiler shall generate a quick-look image product at least once every 15 minutes during instrument operations with, at a minimum, the following characteristics:

a. profiler quick look images will be available to other computers in the local network

b. profiler quick look images will show the three moments (reflectivity, velocity, and velocity standard deviation) as a function of time and height.

Rationale: An image display generation capability is necessary to locally and remotely monitor the instrument data quality and for weather situational awareness in GV field operations.
Verification Method: Demonstration

4.5.16 S-band profiler unattended operations

GV537 The GVS S-band profiler shall operate unattended and shall restart operating without user intervention after a power failure.

Rationale: The GVS will not be staffed on a 24/7 schedule, and precipitation events will occur at random, so the S-band profiler system must provide its own automated restart mechanisms to assure data continuity.
Verification Method: Demonstration

4.6 Instrument Measurement Requirements: UHF Profiler

The GVS UHF profiler will not be required to meet NTIA Manual of Regulations and Procedures for Radio Frequency Management, RSEC-E Criteria. The bandwidth and antenna requirements of RSEC-E are too restrictive for this instrument. A waiver of the requirements will be needed to obtain frequency authorization.

4.6.1 UHF profiler center frequency

GV543 The GVS UHF profiler shall operate at a fixed frequency of 449 MHz ±0.1 MHz.

Rationale: 449 MHz is one of the frequencies pre-approved for profiling radars.
Note: The operating frequency will be crystal controlled.

Note: For an 800 ns pulse width with an 80 ns rise time, typical for a 125 m spatial resolution, the necessary bandwidth for the GVS UHF profiler will be 7.1 MHz.

Verification Method: Documentation

4.6.2 UHF profiler minimum and maximum range

GV549 The GVS UHF profiler radar shall measure at least 50 dBZ without saturating at a minimum range of 200 meters above the ground. The GVS UHF profiler shall collect observations up to 18 km above the ground.

Rationale: See GV371 and GV426.
Verification Method: Testing and analysis

4.6.3 UHF profiler horizontal resolution (beamwidth)

GV553 The GVS UHF profiler shall have a maximum half-power beamwidth of 9 degrees.

Rationale: 9 degrees is a nominal half-power beam width for an UHF profiler. It provides a spatial resolution of 3 km at maximum vertical range, which allows bin-bin comparisons with the X-band and S-band scanning radars and the DPR.

4.6.4 UHF profiler vertical resolution

GV556 The GVS UHF profiler shall have a minimum vertical resolution of 125 meters.

Rationale: This is the resolution of the GPM PR at nadir.
Verification Method: Testing and analysis

4.6.5 UHF profiler minimum reflectivity sensitivity (dBZ)-precipitation

GV560 The GVS UHF profiler shall measure at least 50 dBZ without saturating at a minimum range of 200 meters above the ground.

Rationale: See GV371 and GV426.
Verification Method: Testing and analysis

4.6.6 UHF profiler minimum reflectivity sensitivity (dBZ)-no precipitation

GV564 The GVS UHF profiler shall measure a minimum return of ≤ -15 dBZ at a range of 5 km in the absence of precipitation (Bragg Scattering).

Rationale: This level of sensitivity is required to retrieve vertical air motion below the freezing level.
Verification Method: Testing and analysis

4.6.7 UHF profiler calibration stability

GV568 The GVS UHF profiler shall maintain a stable reflectivity accuracy of less than 2 dBZ.

Rationale: The GVS will have limited support for recalibration of field instrumentation, and precipitation events will occur at random, so the UHF profiler needs stable calibration precision. 2 dBZ is the maximum allowable drift to give meaningful reflectivity intercomparisons with PR/DPR and compute rain rates from the ground radar.
Verification Method: Testing and analysis

4.6.8 UHF profiler unambiguous range

GV572 The GVS UHF profiler shall have a maximum unambiguous range greater than 18 km.

Rationale: The profiler should match the GPM DPR, which will provide data coverage from the surface up to 18 km above ground.
Verification Method: Testing and analysis

4.6.9 UHF profiler dwell time

GV576 The GVS UHF profiler shall dwell for less than 30 seconds.

Rationale: A complete profiler of Doppler spectra and spectral moments will be recorded for each dwell period. These Doppler spectra are used to estimate the Gamma function DSD specified in requirements GV219 through GV240.
Verification Method: Testing and analysis

4.6.10 UHF profiler Nyquist Doppler velocity and spectral resolution

GV580 The GVS UHF profiler shall have a minimum Nyquist velocity ≥16 ms-1 and a maximum Doppler velocity spectral resolution (Doppler velocity bin spacing) less than 0.15 ms-1.

Rationale: See GV454.
Verification Method: Testing and analysis

4.6.11 UHF profiler access to spectra for near real time analysis

GV584 The GVS UHF profiler shall make the observed Doppler velocity spectra available for analysis within ≤60 minutes of the observation.

Rationale: Required for quick look and verification of instrument operations. 60 minutes is the current best practices for the NOAA Hydrometeorological Testbed-West. The goal is 15 minutes.
Verification Method: Demonstration

4.6.12 UHF profiler local archive

GV588 The GVS UHF profiler shall have a local storage capacity with a minimum capacity sufficient to store 30 days of continuous data

Rationale: The GVS will not be staffed on a 24/7 schedule, and precipitation events will occur at random, so the UHF profiler system must provide its own data collection and storage mechanisms to assure data continuity.
Verification Method: Inspection

4.6.13 UHF profiler back-up archive

GV592 The GVS UHF profiler shall maintain a back-up copy of all data collected and generated.

Rationale: A local back-up of the UHF profiler data ensures that any loss of data during transportation for off-site archival and analysis would not be catastrophic. Automatic copying of the data from the radar processor to the renewable storage devices will be part of the software.
Verification Method: Demonstration

4.6.14 UHF profiler quick-look image product

GV596 The GVS S-band profiler shall generate a quick-look image product at least once every 15 minutes during instrument operations with, at a minimum, the following characteristics
a. profiler quick look images will be available to other computers in the local network
b. profiler quick look images will show the three moments (reflectivity, velocity, and velocity standard deviation) as a function of time and height.

Rationale: An image display generation capability is necessary to locally and remotely monitor the instrument data quality and for weather situational awareness in GV field operations.
Verification Method: Demonstration

4.6.15 UHF profiler unattended operation

GV602 The GVS UHF profiler shall operate unattended and shall restart operating without user intervention after a power failure.

Rationale: The GVS will not be staffed on a 24/7 schedule, and precipitation events will occur at random, so the UHF profiler system must provide its own automated restart mechanisms to assure data continuity.
Verification Method: Demonstration

4.7 Instrument Measurement Requirements: Precipitation Gauge and Disdrometer Network

4.7.1 Precipitation gauge network temporal resolution

GV607 Each GVS precipitation gauge shall record data at ≤1 minute intervals.

Rationale: High time resolution rain gauge accumulation data with negligible time offset between locations is needed to validate instantaneous rain rates from GPM and ground-based radar. The ≤1 minute requirement also ensures compatibility with GV1575.
Note: Instrument uncertainty (precision/accuracy) will be defined in a Instrument Handbook, per requirement GV120.

Verification Method: Testing and analysis

4.7.2 Precipitation gauge data distribution

GV612 The GVS precipitation gauges shall be equipped with recording devices to store data for TBD-1 days. The data will be periodically downloaded from the recording devices and made available over the GVS local network every TBD-1 days.

Rationale: The GVS will not be staffed on a 24/7 schedule, and precipitation events will occur at random, so the precipitation gauge system must provide its own data collection, storage, and delivery mechanisms to assure data continuity.

Verification Method: Demonstration

4.7.3 Disdrometer network

GV616 The GVS disdrometer network shall measure rain drop size spectra as concentration (number of drops/ m3), rain rate (mm/hour) and reflectivity (mm6/m3).

Rationale: The three disdrometer parameters are required for surface validation and intercomparison of the same parameters at higher levels in the atmosphere from remote sensing instrumentation.
Verification Method: Demonstration

4.7.4 Disdrometer drop size measurements

GV620 The GVS disdrometer network shall measure rain drop size spectra in a minimum of 20 levels for rain rates from a minimum of 0.3 mm/hour to a maximum of 5.4 mm/hour with a minimum temporal resolution of 1 minute.

Rationale: High time/magnitude resolution disdrometer drop size data with negligible time offset between sources is needed to validate instantaneous rain rates from GPM and ground-based radar. The rain rates are commonly reported values e.g., Munchak and Tokay, J. Applied Meteorology and Climatology, Jan 2008 223-239) and DOE Disdrometer and Tipping Bucket Rain Gauge Handbook, January 2006, DOE/SC-ARM/TR-079 (DOE max drop size = 5.3 mm).
Verification Method: Testing and analysis

4.7.5 Disdrometer data distribution

GV624 The GVS disdrometers shall be equipped with recording devices to store data for TBD-1 days. The data will be periodically downloaded from the recording devices and made available over the GVS local network every TBD-1days.

Rationale: The GVS will not be staffed on a 24/7 schedule, and precipitation events will occur at random, so the disdrometer system must provide its own data collection, storage, and delivery mechanisms to assure data continuity.
Verification Method: Inspection

4.8 Instrument Measurement Requirements: Profiling Microwave Radiometer

4.8.1 Radiometer rain mitigation capability

GV629 The GPM GV profiling radiometer shall employ a rain mitigation capability such that temperature and humidity products can be generated during rain events with rates up to 6 mm/hr.

Rationale: The GVS will be attempting to measure atmospheric variables within precipitation events, and rainwater accumulation on the profiling radiometer will greatly degrade the quality of the instrument measurements below the required accuracies unless it is mitigated.

Note: The goal is to employ instruments that have temperature and humidity errors ≤ 3K and 20%, respectively.

Verification Method: Testing and analysis

4.9 Instrument Measurement Requirements: Rawinsonde

4.9.1 Rawinsonde measured variables

GV635 The GVS shall generate a rawinsonde product with, at a minimum, the following characteristics:
a. measure soundings in wind speed (ms-1), wind direction (degrees), temperature (K), pressure (mb), relative humidity (percent), and altitude
b. measure soundings in ≤2-second-intervals, beginning at the surface
c. report sounding data either in ASCII in accordance with the Code Form For Temp Rawinsonde Observations in FMH-3 edition FCM-H3-1997, Appendix E-II (i.e., WMO TEMP format FM-35), or in BUFR format.

Rationale: High-time-frequency rawinsonde measurements are required to obtain the best time and space match to the high vertical resolution measurements from the profilers and the PR/DPR. Sounding products in a standard meteorological format will be needed for compatibility with external/user meteorological data analysis and processing systems. Downlink intervals of 1 to 2 seconds are typical of commercially available units.
Verification Method: Demonstration

4.9.2 Rawinsonde measurement accuracies

GV642 The GVS rawinsonde ranges, accuracies, precisions, and resolutions shall not exceed those specified in the Federal Meteorological Handbook No. 3 (FMH-3), edition FCM-H3-1997 (<http://www.ofcm.gov/fmh3/text/default.htm> for the following parameters:
a. wind speed
b. wind direction
c. air temperature
d. relative humidity
e. altitude (and/or geopotential height)
f. pressure

Rationale: Meets minimum industry standard data quality.
Verification Method: Testing and analysis

4.9.3 Rawinsonde flight capability

GV652 The GVS rawinsondes shall be lifted by helium filled balloons of sufficient weight to sample the environment to a minimum pressure of 100 mb.

Rationale: The PR and DPR provide data up to 18 km, which is typically near or above the elevation of the 100 mb isobaric level.
Verification Method: Demonstration

4.9.4 Rawinsonde position tracking

GV656 The GVS rawinsondes shall be tracked via Global Positioning Satellite (GPS) capabilities.

Rationale: Industry standard capability.
Verification Method: Demonstration

4.9.5 Rawinsonde independent surface measurements

GV660 The GVS shall employ portable instrumentation at each GVS rawinsonde launch site to verify the rawinsonde surface measurements of temperature and relative humidity.

Rationale: Pre-flight calibration check is necessary due to rawinsonde instrument package variations.
Verification Method: Demonstration

4.9.6 Rawinsonde data quality control

GV664 The GVS shall employ automate rawinsonde QC procedures to flag potentially spurious data (e.g., unreasonable lapse rates and winds or moisture biases).

Rationale: Anomalous data in original sounding data is common and must be identified and eliminated by quality control algorithms.
Verification Method: Testing and analysis

4.9.7 Communications

GV668 The GVS shall generate raw and quality-controlled rawinsonde data products for a sounding within 6 hours following a balloon launch.

Rationale: Soundings must be available in a timely manner to initialize cloud models and perform data quality evaluations.
Verification Method: Demonstration

4.10 Instrument Measurement Requirements: Aircraft-Based Measurements

Requirements to be added TBD-2.

4.11 Instrument Deployment Requirements

4.11.1 X-band scanning radar location

GV675 The GVS X-band scanning radar shall be located within 60 km from the GVS S-band scanning radar.

Rationale: The X- and S-band radars must scan a common area within a reasonable range of the attenuation-susceptible X-band radar.
Verification Method: Inspection

4.11.2 X-band scanning radar deployment capability

GV679 The GVS X-band scanning radar shall have the capability to stop operations, be stored and ready for transportation to an alternate location within 3 days. After transportation to an alternate location, the X-band radar shall be assembled and ready for operations within 3 days.

Rationale: The GVS field sites will change during the limited lifetime of the intensive GPM GV effort, and down time between locations must be minimal.
Verification Method: Demonstration

4.11.3 S and UHF profiler co-location

GV683 The GVS S-band profiler antenna and GVS UHF profiler antenna shall be located within 20 m of each other and the two systems shall be able to operate simultaneously without interference at this maximum antenna separation.

Rationale: Co-location is necessary for the S-band and UHF profilers to sample the same column of air beginning at the lowest possible altitude.
Verification Method: Inspection and Demonstration

4.11.4 Profiler and scanner co-location

GV687 The GVS S-band profiler antenna and GVS UHF profiler antennas shall be located between 30 and 60 km from the GVS scanning S-band scanning radar.

Rationale: : The S-band and UHF profilers must sample a column of air within the 3-D grid volume of the S-band radar but at a sufficient distance for the scanning radar to sample higher altitudes.
Verification Method: Inspection

4.11.5 Precipitation gauge network design (TBD-1)

Requirement to be added TBD-1.

Verification Method: Inspection

4.11.6 Disdrometer network design (TBD-1)

Requirement to be added TBD-1.

Verification Method: Inspection

4.11.7 Rawinsonde launch configurations

GV699 GVS rawinsonde launch locations shall range from a minimum of one (nominal operation periods) to maximum of 4 to 6 during special observation periods. The launch points shall be located in a configuration which provides a sufficient characterization of the environmental for CRM modeling.

Rationale: The spatial variation of the atmospheric vertical profile must be captured for proper model initialization.
Verification Method: Inspection and Analysis

4.11.8 Rawinsonde launch frequencies

GV703 GVS rawinsonde launch frequency at each site shall range from a minimum of 2 per day (nominal operation periods 00 and 12 UTC) to a maximum of 8 per day (00, 03, 06, 09, 12,15, 18, and 21 UTC) during special observation periods.

Rationale: The temporal variation of the atmospheric vertical profile must be captured for proper model initialization and to match up to the PR/DPR overpasses.
Verification Method: Demonstration

5 VALIDATION NETWORK (VN) REQUIREMENTS

5.1 Overview

The rationale for a GPM Validation Network (VN) is based on a recommendation from the GPM Ground Measurements Advisory Panel. The VN supports the basic GV function for statistical validation of DPR measurements, attenuation correction, and precipitation retrieval algorithms. The VN conducts inter-comparison of reflectivity measurements and derived rain rate from the satellite-borne precipitation radar (TRMM PR in a prototype; GPM DPR in the operational system) and ground based radars, starting with the operational radars in the U.S. National Weather Service network. As agreements for data sharing and quality assurance are put in place, the VN will be extended to include additional ground radar networks from other U.S. and international contributors.

5.2 Data Ingest

5.2.1 Acquire WSR-88D data

GV711 The GVS shall acquire full-scan-volume, full resolution WSR-88D Level-II Reflectivity data, over the national network.

Rationale: Recommendation of the GPM Ground Measurements Advisory Panel, and derived.
Note: NEXRAD Level II Reflectivity data come bundled with Velocity and Spectrum Width, so these fields will also be acquired. Once WSR-88D systems are upgraded to dual polarization capability, the format and content of their Level II data will change. Once the upgrade occurs for a given radar, it is expected GVS will need to acquire the following fields, likely bundled: horizontal polarization reflectivity, vertical polarization reflectivity or differential reflectivity, correlation coefficient, linear depolarization ratio, and specific differential phase.

Priority: Phase-1

Verification Method: Inspection

5.2.2 Acquire TRMM PR data

GV717 The GVS shall acquire TRMM PR 1C-21, 2A-23 and 2A-25 products over the CONUS area.

Rationale: 1C-21 needed for matchup with WSR-88D data as recommended by the GPM Ground Measurements Advisory Panel; 2A-23 is used to populate the national map metadata with fields such as rain type; 2A-25 is used for comparisons with PR/DPR attenuation-corrected data.
Priority: Phase-1

Verification Method: Inspection

5.2.3 Acquire GPM DPR data

GV722 The GVS shall acquire GPM DPR (PR-Ka and PR-Ku) Level 1C Reflectivity and Level 2 Precipitation products over the CONUS area.

Rationale: Derived from Requirement GV717.
Priority: Phase-1

Verification Method: Inspection

5.3 Data Preprocessing

5.3.1 Extract WSR-88D metadata

GV728 The GVS shall extract and store nominal volume scan time, volume coverage pattern (VCP), and product, system, and precipitation state information as metadata for each volume scan.

Rationale: These parameters support the determination of coincident ground and satellite radar data (Reqt. GV765, GV770), and whether the 88D is detecting significant precipitation and/or severe storms. WSR-88D scans in fixed VCPs of fixed duration, depending on the mode (Clear Air, Precipitation, Storm) of the radar.
Priority: Phase-1

Verification Method: Demonstration

5.3.2 Extract TRMM PR metadata

GV733 The GVS shall extract and store the nominal overpass time and other PR product and precipitation state information for each PR overpass covering 20% or more of the ground radar field of view.

Rationale: Supports determination of coincident data sets and time offsets.
Note: The nominal overpass time is defined as the time (year to second) of the closest approach of the satellite subtrack to the ground radar location.

Priority: Phase-1

Verification Method: Demonstration

5.3.3 Extract GPM DPR metadata

GV739 The GVS shall extract and store the nominal overpass time and other DPR product and precipitation state information for each DPR overpass covering 20% or more of the ground radar field of view.

Rationale: Supports determination of coincident data sets and time offsets.
Note: The nominal overpass time is defined as the time (year to second) of the closest approach of the satellite subtrack to the ground radar location. Compare/contrast to GPM PPS Level 3 Draft Requirement M12.5.

Verification Method: Demonstration

Priority: Phase-1

5.3.4 Apply automated quality control

GV745 The GVS shall apply automated quality control to the GV radar data, and record the applied QC methods and results.

Rationale: This is a major function of the TRMM GV procedures required for utilization of ground radar data, and needs to be included in the GPM GVS processing.
Priority: Phase-1

Verification Method: Demonstration

5.3.5 Apply manual quality control

GV750 The GVS shall be able to apply manual quality control to the GV radar data, and record the applied QC methods and results, including:

a. (Accept) the data as-is, overriding any automated QC result

b. Edit and store a manually-corrected version of the product (Accept Corrected)

c. (Reject) the data as bad, overriding any other QC result.

Rationale: This is a major function of the TRMM GV procedures required for utilization of ground radar data, and needs to be included in the GPM GVS processing.
Priority: Phase-1

Verification Method: Demonstration

5.3.6 Maintain QC versions

GV758 The GVS shall store the post-QC and original radar data

Rationale: Derived, facilitates future reprocessing of the ground radar data with improved QC.
Note: It is assumed that a database will be used in the implementation of the Validation Network to store radar data and derived parameters.

Priority: Phase-1

Verification Method: Demonstration

5.4 Data Post-processing and Analysis

5.4.1 Calculate overlap

GV765 The GVS shall determine the actual (km2) and percent areal overlap of the PR (for TRMM) and DPR (for GPM) data coverage with the GR area of coverage within a selected GR range limit.

Rationale: Needed to determine whether the satellite and ground observations are coincident, according to areal overlap thresholds.
Priority: Phase-1

Verification Method: Demonstration

5.4.2 Variable time offset and area overlap thresholds

GV770 The GVS shall apply a set of variable time offset and areal overlap thresholds between DPR and GR data as criteria to determine whether the two data volumes are coincident.

Rationale: This requirement allows exclusion of coincident overpasses from analysis when the areal overlap is too small (i.e., the PR/DPR swath is distant from the ground radar, in locations where the matching ground radar observations are degraded by beam filling issues and beam height uncertainties), or when the time between a ground radar scan and satellite overpass is too large.
Priority: Phase-1/2 (See GV872, GV877)

Note 1: It is assumed that, in the implementation of the Validation Network, a default threshold set and any number of user-specified threshold sets will be able to be stored and retrieved for use within the GVS. The results of any coincident data event determination will also be able to be stored in the GVS, with an identifying link to the given threshold set used.

Note 2: A coincident data event is a PR or DPR overpass of a ground radar site which meets the areal overlap threshold, and includes all PR/DPR and ground radar products within the time offset threshold. It is specific to the threshold set used to determine the data coincidence. It may or may not be an active precipitation event.

Note 3: The default minimum areal overlap is a system-defined parameter.
Compare/contrast to GPM PPS Level 3 Draft Requirements M12.5, M13.1, and M13.2.

Verification Method: Demonstration

5.4.3 Determine fractional area of precipitation

GV778 The GVS shall be able to determine the fractional area of precipitation, relative to the range-limit-defined ground-based radar (GR) area of coverage, and within the DPR/GR overlap area, as detected by: (1) the DPR, (2) the GR, and (3) both the DPR and GR, in common.

Rationale: Needed to determine whether the satellite and ground observations are observing a “rain event.”
Priority: Phase-1

Verification Method: Demonstration

5.4.4 Data transformation and interpolation

GV783 The GVS shall be able to transform and interpolate GPM PR and DPR product data and ground-based radar (GR) data to a common space/ground grid with, at a minimum, the following characteristics:
a: north (y) east (x) and local vertical (z) oriented 3-dimensional Cartesian grid,
b: grid centered on the ground radar location.

Rationale:
Priority: Phase-1

Verification Method: Demonstration

5.4.5 Reflectivity transformation

GV789 GV shall be able to convert reflectivity factor (Z) to and from reflectivity in decibels (dBZ) for interpolation of reflectivity.

Rationale: WRS-88D data comes in dBZ, the transformation algorithms convert to Z to preserve the linearity of the data when re-sampling to the transformed grid.
Priority: Phase-1

Verification Method: Demonstration

5.4.6 Variable parameters for common space/ground grid

GV794 The GVS shall use a set of variable parameters to define the map projection, grid spacing, and dimensions of the common space/ground grid (defined by requirement GV783).

Rationale: Derived.
Note: It is assumed that in the implementation of the Validation Network a default set and any number of user-specified grid parameter sets will be stored and retrieved for use within the GVS.

Priority: Phase-1

Verification Method: Demonstration

5.4.7 Gridded Radar Data Storage

GV800 The Cartesian 3-D grids of GR, PR, and DPR data shall be able to be stored in the GVS database with identifying links to the:
a. input radar data source product(s) (directly, or by attributes-in-common),
b. set of parameters (Reqt. GV783) used to define the 3-D Cartesian grid,
c. set of parameters (Reqt. GV770) used to define data coincidence, and the
d. coincident data event itself, as defined by the coincidence parameters.

Rationale: This provides the necessary flexibility in the cross-comparison (matchup) of coincident ground and space radar data under differing comparison criteria, without the need to re-create the grids.
Note: Item (c) may be optional if (d) provides the necessary links by association. Item (d) serves to link coincident grids of different data sources to one another.

Priority: Phase-1

Verification Method: Inspection

5.4.8 Grid Metadata

GV810 The GVS shall analyze characteristics of data in the 3-D grids and produce descriptive metadata based on these analyses.
a. Percentage of the horizontal grid area within which precipitation is present, based on a reflectivity threshold, for each vertical level in the 3-D grid

b. Percentage of the 3-D grid in which overlapping PR or DPR data are available (partial overlap coverage will be allowed and is likely to be the norm)
c. Maximum and minimum vertical grid levels where the bright band occurs within the 3-D grid
d. Percent missing data in each level of the 3-D grid
e. Type(s) of precipitation (convective, stratiform, etc.) present in the 3-D grid (this in itself may be a 2-D array indicating the dominant precipitation type in each vertical column of the 3-D grid)

Rationale: Grid metadata are needed to support the analysis and metrics reporting functions in the reflectivity comparison product generation.
Note 1: It is assumed that the metadata elements will be stored in the GVS database with links to the related 3-D grids, and by association, to the matchup radar products from which the 3-D grids are produced. Also, storage retention of the metadata elements in the database will match those of the 3-D grids from which they were derived.

Note 2: Example metadata to be derived from the data in the 3-D grids include:

Priority: Phase-1/2 (complex parameters like bright band and precipitation type deferred to Phase-2)

Verification Method: Demonstration

5.4.9 Alignment

GV822 The GVS shall be able to align DPR and GR 3-D data volumes to achieve a best fit to minimize earth-location and pointing uncertainties in the DPR data.

Rationale: Research by Chandrasekar and others suggests that affine transformation of the input data can reduce errors introduced by uncertainties in the ground- and space-based viewing geometries.
Priority: Phase-2

Verification Method: Demonstration

5.4.10 Averaging

GV827 The GVS shall be able to average 3-D gridded radar data in the vertical and horizontal dimensions.

Rationale: Reference 2.
Priority: Phase-2

Verification Method: Demonstration

5.4.11 Extract vertical profiles

GV832 The GVS shall be able to extract vertical profiles from the 3-D Cartesian gridded radar data.

Rationale: Reference 2.
Priority: Phase-2

Verification Method: Demonstration

5.4.12 Exclude selected observations

GV837 The GVS shall be able to exclude grid cells from the matchup analysis based on selectable criteria, at a minimum:

a. storm type,

b. reflectivity or reflectivity factor limits

c. presence or absence of a bright band

d. poor correlation of ground and satellite reflectivity fields.

Rationale: There is a need to segregate the matchup data into categories based on these criteria to minimize the within-group variability.

Priority: Phase-2

Verification Method: Demonstration

5.4.13 Reflectivity Comparison Products

GV846 The GVS shall be able to perform matchup analysis of reflectivity from satellite and ground radars to produce the comparison product including, at a minimum:

a. Scatter plots of satellite vs. ground radar reflectivity

b. Time series of mean monthly bias of WSR-88D reflectivity relative to PR/DPR

c. Plots of mean ground-satellite reflectivity difference vs. PR/DPR reflectivity category

d. Vertical profiles of mean ground-satellite reflectivity difference.

Rationale:

Priority: Phase-2

Verification Method: Demonstration

5.4.14 Automated QC in Comparison Products

GV854 The GVS shall perform quality control with reflectivity comparison product generation to determine, as best as possible, whether there are significant geolocation errors (for PR/DPR reflectivity) or anomalous echoes (anomalous propagation, ground clutter, etc.) from the ground radar.

Rationale: Derived.

Note: Where possible errors exceed defined thresholds, the affected 3-D grids will be flagged in the database and excluded from the product results. A summary (Date/time, data type, QC check failed) of excluded grid data will be produced for the default output product and stored in the database as metadata associated with the product. The output display products will indicate, at a minimum, the number of grid pairs excluded from the results due to failure of QC checks.

Priority: Phase-2

Verification Method: Demonstration

5.4.15 Manual Override QC flags

GV860 The GVS shall provide an option to manually override the individual 3-D grid QC flags which result from the automated reflectivity comparison QC checks from a prior product generation run.

Rationale: Derived.
Note: This option would be exercised, for example, in the case where the manual override is used to force the inclusion of 3-D grid data otherwise flagged for rejection by automated QC. In that case, the manual override data will be included in the results when the output display product is regenerated.

Priority: Phase-2

Verification Method: Demonstration

5.4.16 Reflectivity Comparison Product Storage

GV866 The GVS shall store scheduled, default reflectivity comparison products as they are completed.

Rationale: Derived.
Priority: Phase-1 (3-D grids); Phase-2 (comparisons)

Verification Method: Demonstration

5.5 Scheduled and Interactive Capabilities

5.5.1 Default parameters for coincident data

GV872 The GVS shall use a default set of parameters to define coincident data in routine, scheduled processing.

Rationale: Derived.
Priority: Phase-1

Verification Method: Inspection

5.5.2 User-defined parameters for coincident data

GV877 The GVS shall allow authorized users to create, save, edit and retrieve custom parameter sets, and select a custom set to be applied to determine coincident data in a user-initiated run.

Rationale: Derived.
Priority: Phase-2

Verification Method: Demonstration

5.5.3 Default parameters for common space/ground grid

GV882 The GVS shall use a default parameter set for defining the 3-D Cartesian grid in routine, scheduled processing.

Rationale: Derived.
Priority: Phase-1

Verification Method: Inspection

5.5.4 Default and user parameters for common space/ground grid

GV887 The GVS shall allow authorized users to create, save, edit and retrieve custom parameter sets, and select a custom set to be applied to generate 3-D grids in a user-initiated run.

Rationale: Derived.
Priority: Phase-2

Verification Method: Demonstration

5.5.5 Manual Quality Control

GV892 The GVS shall provide the capability to display and manually quality control WSR-88D radar data, including the ability to edit the product and override the automated quality control flags to force inclusion and exclusion of the product.

Rationale: Derived.
Priority: Phase-1

Verification Method: Demonstration

5.5.6 Routine Process Initiation

GV897 GVS data ingest, preprocessing, automated QC, post-processing, and comparison product creation for the Validation Network shall be performed automatically, triggered by the availability of new data or scheduled by the system.

Rationale: Derived.
Priority: Phase-1

Verification Method: Demonstration

5.5.7 Non-Routine Process Initiation

GV902 Authorized users shall be able to initiate post-processing and comparison product creation on demand and specify all necessary parameters to define the subset of data to process and the products to be produced,.

Rationale: Derived.
Priority: Phase-2

Verification Method: Demonstration

5.5.8 User Access to Standard Validation Network Data Products

GV907 The GVS shall provide to the public an online catalog of reflectivity comparison display products, from which products may be selected, viewed, and downloaded.

Rationale:
Priority: Phase-1

Verification Method: Demonstration

5.6 Validation Network Performance and Responsiveness

5.6.1 Availability of Default Validation Network Data Products

GV912 The GVS shall generate Validation Network raw and gridded products within 24 hours of receipt of required input data.

Rationale: As there is little statistical significance in individual cases, and near-real-time methods exist of viewing the input data outside of the VN capabilities, 24 hours is reasonable for an automated processing system and the level of complexity of VN data processing.
Note: The VN products include metadata with default QC applied.

Verification Method: Demonstration

5.6.2 User Requests for Non-Routine Data and Data Processing

GV917 The GVS shall respond to PMM Science Team requests for non-standard products within two (2) working days.

Rationale: The VN will have limited staffing and has no requirement for real-time data availability.
Note: Non-standard products include those for products that are not routinely produced, stored, or otherwise available in the online catalog. It is the goal of the VN to fulfill such user requests within three (3) working days it if no re-coding is required. Requests for non-standard products from users other than PMM Science Team members will be acknowledged within 2 working days, and will be reviewed by the PMM Project Scientist (or designee) for completion on an “as resources are available” basis.

Verification Method: Demonstration

6 APPENDIX A - ACRONYMS AND SYMBOLS

ACRONYM	DEFINITION
3-D	3-Dimension
A&D	Archive and Distribution
AGL	Above Ground Level
ARM	Atmospheric Radiation Measurement
ASCII	American Standard Code for Information Interchange
cm	centimeter
CM	Configuration Management
CMO	Configuration Management Office
CONUS	Continental United States
CRM	Cloud Resolving Model
D0	Median drop diameter
dB	Decibel
dBZ	Reflectivity in decibels
DOE	Department of Energy
DPR	Dual-frequency Precipitation Radar
DSD	Drop Size Distribution
FMH-3	Federal Meteorological Handbook, No. 3
g	gram
GCM	Global Climate Model
GHz	Gigahertz

ACRONYM	DEFINITION
GMI	Global Microwave Imager
GPM	Global Precipitation Measurement
GPS	Global Positioning System
GR	Ground Radar
GSFC	Goddard Space Flight Center
GV	Ground Validation
GVS	Ground Validation System
hr	Hour
JAXA	Japanese Aerospace Exploration Agency
JWD	Joss-Waldvogel Disdrometer
K	Kelvin
Kdp	Specific Differential Phase
km	kilometer
L2	Level-2
LDR	Linear Depolarization Ratio
m	Meter
MAR	Mission Assurance Requirements
mb	Millibar
MHz	Megahertz
mm	Millimeter
ms^{-1}	Meters per second
NASA	National Aeronautics and Space Administration

ACRONYM	DEFINITION
NEXRAD	Next Generation Weather Radar (a.k.a WSR-88D)
NTIA	National Telecommunications and Information Administration
ns	Nanosecond
NTP	Network Time Protocol
PMM	Precipitation Measuring Missions
PPI	Plan Position Indicator
PPS	Precipitation Processing System
PR	Precipitation Radar
QC	Quality Control
RSEC-E	Radar Spectrum Engineering Criteria, Item E
rZdr	Resampled differential reflectivity factor
rZh	Resampled equivalent reflectivity factor horizontal polarization
rZv	Resampled equivalent reflectivity factor vertical polarization
s, sec	Second
SSM	Satellite Simulator Model
STSR	Simultaneous Transmission and Simultaneous Reception
STAR	Simultaneous Transmission Alternate Reception
TBD	To Be Determined
TRMM	Tropical Rainfall Measuring Mission
UHF	Ultra High Frequency
VCP	Volume Coverage Pattern
VN	Validation Network

ACRONYM	DEFINITION
WSR-88D	Weather Surveillance Radar - 1988 Doppler (a.k.a. NEXRAD)
WMO	World Meteorological Organization
Z	Reflectivity Factor
Zdr (rZdr)	Differential reflectivity factor (resampled)
Zh (rZh)	Equivalent reflectivity factor horizontal polarization (resampled)
Zv (rZv)	Equivalent reflectivity factor vertical polarization (resampled)
_dp	Differential propagation phase
_hv	Correlation coefficient of the horizontal and vertical return signal

7 APPENDIX B - WORK-OFF PLAN

TBD-1	The specific requirements for the gauge and disdrometer network design and related requirements (GVS-3.11.20, GVS3.11.25) as well as the gauge and disdrometer recording device storage capacity (GVS-3.7.35, GVS-3.7.55) have yet to be determined. It is known, however, that the GVS precipitation gauge network will need to have a flexible design to accommodate different site locations and cold vs. warm precipitation. The network must be designed to measure the variability of precipitation accumulation (mm/hour) within the area of an interpolated radar pixel (defined in requirements GVS-1.05 and GVS-1.10) as well as within a larger area sampled by the scanning radars. The rain gauges will be distributed into clusters (each cluster will be approximately 100 km^2, depending on individual site characteristics) at ranges extending from roughly 30-120 km from the radars (the exact number of clusters with depend on the site location). Data from within each cluster will be used to evaluate the sub-pixel spatial variability of rainfall while the combined cluster data will be used to quantify range errors in the radar precipitation products. The spatial density of precipitation gauges within each cluster will vary from site to site but will have a minimum of 1 gauge per TBD m2 (warm precipitation) and 1 gauge per TBD m^2 (cold precipitation) within the area of an interpolated radar pixel. The GVS disdrometer network will have a flexible design to accommodate different site locations and cold vs. warm precipitation. The network will also be designed to measure the variability of precipitation size characteristics within the area of an interpolated radar pixel (defined in requirements 1.05 and 1.10) as well as within a larger area sampled by the scanning radars. The disdrometers will be embedded within the same rain gauge clusters (defined in requirement 10.20) to evaluate the sub-pixel spatial variability of rainfall characteristics as well as to quantify range errors in the radar precipitation products. The spatial density of disdrometers within each cluster will vary from site to site but will have a minimum of 1 disdrometer per some TBD m2 (warm precipitation) and 1 disdrometer per some other TBD m^2 (cold precipitation) within the area of an interpolated radar pixel. Additional review of the literature and discussion with gauge/disdrometer network experts is on-going. It is expected that this requirement will be finalized well before GPM Mission PDR, and that the implementation of the requirement will fit within the current GPM GVS budget.

	TBD-2	Specific requirements for GVS aircraft-based measurements (Section 3.10) have yet to be determined. It is generally assumed that both microphysical and remote sensing measurements will need to be made. Microphysical measurements will need to be made within the clouds, while remote sensing measurements are typically made from above the could tops. Thus it is assumed that a minimum of two aircraft will be required. Microphysical measurements could include: • Ice particle concentrations: 20 microns - 2 cm • Cloud/Rainwater particle concentrations: 2 microns to 8 mm • Horizontal and Vertical velocity: +/- 1 m/s • Temperature/moisture profiling (dropsonde or in-situ flight sampling) • Liquid water content (g/m^3 down to 0.1 g/m^3) includes supercooled water • CCN/IN measurements (concentration, size and type) • Remote sensing measurements could include: • Multi-frequency downward looking radiometers • Multi-frequency scanning polarimetric radar (X, Ka/u, W bands, with gate spacing ≤ 50 m) The GVS manager recently registered with the NASA airborne science program and reserved aircraft time for the 2011 GVS field campaign. Additional information is being sought over the next few weeks from discipline experts to understand and refine the GVS requirements for airborne microphysical and remote sensing measurements. It is expected that this requirement will be finalized well before GPM Mission PDR, and that the implementation of the requirement will fit within the current GPM GVS budget.

8 APPENDIX C - REQUIREMENTS TRACEABILITY

Parent Requirement	Requirement
MRD543/7.4.3.1.0-1/Ready for operations	GV43/2.1.1.0-1/Ready for operations
MRD545/7.4.3.2.0-1/Operations lifetime	GV48/2.1.2.0-1/Operations lifetime
MRD534/7.4.2.3.0-1/Archive MRD538/7.4.2.5.0-1/Distribution	GV52/2.1.3.0-1/Secure data rights
MRD534/7.4.2.3.0-1/Archive MRD536/7.4.2.4.0-1/Archive search and order MRD538/7.4.2.5.0-1/Distribution	GV56/2.1.4.0-1/Mange data policies and procedures
MRD552/7.4.4.1.0-1/New and updated instruments and methods	GV60/2.1.5.0-1/Conduct configuration management
MRD534/7.4.2.3.0-1/Archive	GV67/3.1.0-1/A&D contents
MRD534/7.4.2.3.0-1/Archive	GV74/3.2.0-1/A&D ingest capability
MRD534/7.4.2.3.0-1/Archive	GV78/3.3.0-1/A&D archive capability
MRD536/7.4.2.4.0-1/Archive search and order	GV82/3.4.0-1/A&D search and order capability
MRD538/7.4.2.5.0-1/Distribution	GV86/3.5.0-1/A&D distribution capability
MRD561/7.4.5.2.0-1/Interface to the PMM Science Team	GV90/3.6.0-1/A&D user services capability for PMM Science Team Members
MRD540/7.4.2.6.0-1/Metrics	GV94/3.7.0-1/A&D metrics capability
MRD554/7.4.4.2.0-1/Product generation timeliness MRD556/7.4.4.3.0-1/Product distribution timeliness	GV98/3.8.0-1/A&D data delivery time-line
MRD554/7.4.4.2.0-1/Product generation timeliness MRD556/7.4.4.3.0-1/Product distribution timeliness	GV102/3.9.0-1/A&D electronic data delivery
MRD549/7.4.3.4.0-1/Transition to long-term archive	GV106/3.10.0-1/A&D long-term archive
MRD534/7.4.2.3.0-1/Archive MRD538/7.4.2.5.0-1/Distribution	GV110/3.11.0-1/Check validity of data received
MRD534/7.4.2.3.0-1/Archive MRD538/7.4.2.5.0-1/Distribution	GV114/3.12.0-1/Check validity of data distributed
MRD552/7.4.4.1.0-1/New and updated instruments and methods	GV120/4.1.1.0-1/Instrument Documentation
MRD552/7.4.4.1.0-1/New and updated instruments and methods	GV133/4.1.2.0-1/File date/time stamps
MRD552/7.4.4.1.0-1/New and updated instruments and methods	GV138/4.1.3.0-1/Measurement time stamps
MRD534/7.4.2.3.0-1/Archive MRD536/7.4.2.4.0-1/Archive search and order MRD538/7.4.2.5.0-1/Distribution	GV143/4.1.4.0-1/Network Time Protocol (NTP) Server
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV149/4.2.1.1.0-1/X-band scanning radar product Cartesian grid
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV157/4.2.1.2.0-1/S-band scanning radar product Cartesian grid
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements	GV165/4.2.1.3.0-1/X-band re-sampled equivalent reflectivity factor product

Parent Requirement	Requirement
for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV170/4.2.1.4.0-1/X-band re-sampled differential reflectivity product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV175/4.2.1.5.0-1/X-band scanning radar specific differential phase product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV180/4.2.1.6.0-1/S-band re-sampled equivalent reflectivity factor product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV185/4.2.1.7.0-1/S-band re-sampled differential reflectivity product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV190/4.2.1.8.0-1/S-band scanning radar specific differential phase product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV195/4.2.1.9.0-1/Scanning radar liquid water content product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV199/4.2.1.10.0-1/Scanning radar hydrometeor identification product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV205/4.2.1.11.0-1/Scanning radar median drop diameter product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV210/4.2.1.12.0-1/Scanning radar instantaneous rain rate product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV215/4.2.1.13.0-1/Scanning radar number concentration - liquid product

Parent Requirement	Requirement
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV219/4.2.1.14.0-1/S and UHF band profiler pair median particle diameter product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV226/4.2.1.15.0-1/S and UHF band profiler pair particle concentration product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV233/4.2.1.16.0-1/S and UHF band profiler pair shape parameter product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV240/4.2.1.17.0-1/S and UHF band profiler pair vertical air motion product
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV246/4.2.1.18.0-1/Disdrometer particle diameter product
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV250/4.2.1.19.0-1/Disdrometer number concentration product
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV254/4.2.1.20.0-1/Disdrometer rain rate product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications MRD532/7.4.2.2.0-1/Product Generation	GV258/4.2.1.21.0-1/Disdrometer radar reflectivity product
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV262/4.2.1.22.0-1/Rain gauge rain rate product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV266/4.2.1.23.0-1/Profiling microwave radiometer temperature profiles product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV273/4.2.1.24.0-1/Profiling microwave radiometer water vapor concentration profiles product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV280/4.2.2.1.0-1/X-band scanning radar equivalent reflectivity factor product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV285/4.2.2.2.0-1/X-band scanning radar differential reflectivity product

Parent Requirement	Requirement
MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV290/4.2.2.3.0-1/X-band scanning radar differential propagation phase product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV295/4.2.2.4.0-1/X-band scanning radar co-polar correlation coefficient product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV300/4.2.2.5.0-1/X-band scanning radar linear depolarization ratio product (optional)
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV306/4.2.2.6.0-1/X-band scanning radar Doppler radial velocity product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV311/4.2.2.7.0-1/S-band scanning radar equivalent reflectivity factor product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV316/4.2.2.8.0-1/S-band scanning radar differential reflectivity product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV321/4.2.2.9.0-1/S-band scanning radar differential propagation phase product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV326/4.2.2.10.0-1/S-band scanning radar horizontal-vertical correlation coefficient product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV331/4.2.2.11.0-1/S-band scanning radar linear depolarization ratio product (optional)
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation	GV337/4.2.2.12.0-1/S-band scanning radar Doppler radial velocity product

Parent Requirement	Requirement
MRD532/7.4.2.2.0-1/Product Generation	
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV342/4.2.2.13.0-1/S-band profiler Doppler spectra product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV346/4.2.2.14.0-1/S-band profiler spectral moments product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV350/4.2.2.15.0-1/UHF profiler Doppler spectra product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV354/4.2.2.16.0-1/UHF profiler precipitation spectral moments product
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates MRD525/7.4.1.2.0-1/Precipitation physics measurements for satellite observation simulation MRD532/7.4.2.2.0-1/Product Generation	GV358/4.2.2.17.0-1/UHF profiler vertical air motion product
MRD530/7.4.2.1.0-1/Measurement	GV363/4.3.1.0-1/X-band scanning radar center frequency
MRD530/7.4.2.1.0-1/Measurement	GV367/4.3.2.0-1/X-band scanning radar minimum and maximum elevation
MRD530/7.4.2.1.0-1/Measurement	GV371/4.3.3.0-1/X-band scanning radar minimum and maximum range
MRD530/7.4.2.1.0-1/Measurement	GV375/4.3.4.0-1/X-band scanning radar elevation pointing accuracy
MRD530/7.4.2.1.0-1/Measurement	GV379/4.3.5.0-1/X-band scanning radar elevation pointing uncertainty
MRD530/7.4.2.1.0-1/Measurement	GV383/4.3.6.0-1/X-band scanning radar azimuth pointing accuracy
MRD530/7.4.2.1.0-1/Measurement	GV387/4.3.7.0-1/X-band scanning radar azimuth pointing uncertainty
MRD530/7.4.2.1.0-1/Measurement	GV391/4.3.8.0-1/X-band scanning radar range resolution
MRD530/7.4.2.1.0-1/Measurement	GV395/4.3.9.0-1/X-band scanning radar horizontal/vertical resolution
MRD530/7.4.2.1.0-1/Measurement	GV399/4.3.10.0-1/X-band scanning radar calibration stability
MRD530/7.4.2.1.0-1/Measurement	GV403/4.3.11.0-1/X-band scanning radar scan rates
MRD530/7.4.2.1.0-1/Measurement	GV407/4.3.12.0-1/X-band scanning radar full volume scan time
MRD532/7.4.2.2.0-1/Product Generation	GV412/4.3.13.0-1/Communications

Parent Requirement	Requirement
MRD530/7.4.2.1.0-1/Measurement	GV418/4.4.1.0-1/S-band scanning radar center frequency
MRD530/7.4.2.1.0-1/Measurement	GV422/4.4.2.0-1/S-band scanning radar minimum and maximum range
MRD530/7.4.2.1.0-1/Measurement	GV426/4.4.3.0-1/S-band scanning radar minimum and maximum elevation
MRD530/7.4.2.1.0-1/Measurement	GV430/4.4.4.0-1/S-band scanning radar range resolution
MRD530/7.4.2.1.0-1/Measurement	GV434/4.4.5.0-1/S-band scanning radar horizontal/vertical resolution
MRD530/7.4.2.1.0-1/Measurement	GV438/4.4.6.0-1/S-band scanning radar azimuth pointing accuracy
MRD530/7.4.2.1.0-1/Measurement	GV442/4.4.7.0-1/S-band scanning radar azimuth pointing uncertainty
MRD530/7.4.2.1.0-1/Measurement	GV446/4.4.8.0-1/S-band scanning radar elevation pointing accuracy
MRD530/7.4.2.1.0-1/Measurement	GV450/4.4.9.0-1/S-band scanning radar elevation pointing uncertainty
MRD530/7.4.2.1.0-1/Measurement	GV454/4.4.10.0-1/S-band scanning radar calibration stability
MRD530/7.4.2.1.0-1/Measurement	GV458/4.4.11.0-1/S-band scanning radar full volume scan time
MRD532/7.4.2.2.0-1/Product Generation	GV463/4.4.12.0-1/S-band scanning radar scan rates
MRD530/7.4.2.1.0-1/Measurement	GV467/4.4.13.0-1/Communications
MRD530/7.4.2.1.0-1/Measurement	GV473/4.5.1.0-1/S-band profiler center frequency
MRD530/7.4.2.1.0-1/Measurement	GV477/4.5.2.0-1/S-band profiler bandwidth
MRD530/7.4.2.1.0-1/Measurement	GV481/4.5.3.0-1/S-band profiler minimum and maximum range
MRD530/7.4.2.1.0-1/Measurement	GV485/4.5.4.0-1/S-band profiler antenna (beamwidth)
MRD530/7.4.2.1.0-1/Measurement	GV489/4.5.5.0-1/S-band profiler antenna shroud
MRD530/7.4.2.1.0-1/Measurement	GV494/4.5.6.0-1/S-band profiler vertical resolution
MRD530/7.4.2.1.0-1/Measurement	GV498/4.5.7.0-1/S-band profiler minimum reflectivity sensitivity (dBZ)
MRD530/7.4.2.1.0-1/Measurement	GV502/4.5.8.0-1/S-band profiler calibration stability
MRD530/7.4.2.1.0-1/Measurement	GV507/4.5.9.0-1/S-band profiler unambiguous range
MRD530/7.4.2.1.0-1/Measurement	GV511/4.5.10.0-1/S-band profiler dwell time
MRD530/7.4.2.1.0-1/Measurement	GV515/4.5.11.0-1/S-band profiler Nyquist Doppler velocity and spectral resolution
MRD530/7.4.2.1.0-1/Measurement	GV519/4.5.12.0-1/S-band profiler access to spectra for real time analysis
MRD530/7.4.2.1.0-1/Measurement	GV523/4.5.13.0-1/S-band profiler local archive
MRD530/7.4.2.1.0-1/Measurement	GV527/4.5.14.0-1/S-band profiler back-up archive
MRD530/7.4.2.1.0-1/Measurement	GV531/4.5.15.0-1/S-band profiler quick-look image product

Parent Requirement	Requirement
MRD530/7.4.2.1.0-1/Measurement	GV537/4.5.16.0-1/S-band profiler unattended operations
MRD530/7.4.2.1.0-1/Measurement	GV543/4.6.1.0-1/UHF profiler center frequency
MRD530/7.4.2.1.0-1/Measurement	GV549/4.6.2.0-1/UHF profiler minimum and maximum range
MRD530/7.4.2.1.0-1/Measurement	GV553/4.6.3.0-1/UHF profiler horizontal resolution (beamwidth)
MRD530/7.4.2.1.0-1/Measurement	GV556/4.6.4.0-1/UHF profiler vertical resolution
MRD530/7.4.2.1.0-1/Measurement	GV560/4.6.5.0-1/UHF profiler minimum reflectivity sensitivity (dBZ)-precipitation
MRD530/7.4.2.1.0-1/Measurement	GV564/4.6.6.0-1/UHF profiler minimum reflectivity sensitivity (dBZ)-no precipitation
MRD530/7.4.2.1.0-1/Measurement	GV568/4.6.7.0-1/UHF profiler calibration stability
MRD530/7.4.2.1.0-1/Measurement	GV572/4.6.8.0-1/UHF profiler unambiguous range
MRD530/7.4.2.1.0-1/Measurement	GV576/4.6.9.0-1/UHF profiler dwell time
MRD530/7.4.2.1.0-1/Measurement	GV580/4.6.10.0-1/UHF profiler Nyquist Doppler velocity and spectral resolution
MRD530/7.4.2.1.0-1/Measurement	GV584/4.6.11.0-1/UHF profiler access to spectra for near real time analysis
MRD547/7.4.3.3.0-1/Nominal operations	GV588/4.6.12.0-1/UHF profiler local archive
MRD547/7.4.3.3.0-1/Nominal operations	GV592/4.6.13.0-1/UHF profiler back-up archive
MRD547/7.4.3.3.0-1/Nominal operations	GV596/4.6.14.0-1/UHF profiler quick-look image product
MRD547/7.4.3.3.0-1/Nominal operations	GV602/4.6.15.0-1/UHF profiler unattended operation
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV607/4.7.1.0-1/Precipitation gauge network temporal resolution
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV612/4.7.2.0-1/Precipitation gauge data distribution
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV616/4.7.3.0-1/Disdrometer network
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV620/4.7.4.0-1/Disdrometer drop size measurements
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV624/4.7.5.0-1/Disdrometer data distribution
MRD530/7.4.2.1.0-1/Measurement	GV629/4.8.1.0-1/Radiometer rain mitigation capability
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV635/4.9.1.0-1/Rawinsonde measured variables
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV642/4.9.2.0-1/Rawinsonde measurement accuracies
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV652/4.9.3.0-1/Rawinsonde flight capability
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV656/4.9.4.0-1/Rawinsonde position tracking
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV660/4.9.5.0-1/Rawinsonde independent surface measurements
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV664/4.9.6.0-1/Rawinsonde data quality control

Parent Requirement	Requirement
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV668/4.9.7.0-1/Communications
MRD530/7.4.2.1.0-1/Measurement	GV675/4.11.1.0-1/X-band scanning radar location
MRD530/7.4.2.1.0-1/Measurement	GV679/4.11.2.0-1/X-band scanning radar deployment capability
MRD530/7.4.2.1.0-1/Measurement	GV683/4.11.3.0-1/S and UHF profiler co-location
MRD530/7.4.2.1.0-1/Measurement	GV687/4.11.4.0-1/Profiler and scanner co-location
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV699/4.11.7.0-1/Rawinsonde launch configurations
MRD527/7.4.1.3.0-1/Assessment of satellite precipitation estimates in hydrological applications	GV703/4.11.8.0-1/Rawinsonde launch frequencies
MRD563/7.4.5.3.0-1/Ancillary Data	GV711/5.2.1.0-1/Acquire WSR-88D data
MRD559/7.4.5.1.0-1/Interface to the PPS MRD561/7.4.5.2.0-1/Interface to the PMM Science Team MRD563/7.4.5.3.0-1/Ancillary Data	GV717/5.2.2.0-1/Acquire TRMM PR data
MRD559/7.4.5.1.0-1/Interface to the PPS MRD561/7.4.5.2.0-1/Interface to the PMM Science Team MRD563/7.4.5.3.0-1/Ancillary Data	GV722/5.2.3.0-1/Acquire GPM DPR data
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV728/5.3.1.0-1/Extract WSR-88D metadata
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV733/5.3.2.0-1/Extract TRMM PR metadata
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV739/5.3.3.0-1/Extract GPM DPR metadata
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV745/5.3.4.0-1/Apply automated quality control
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV750/5.3.5.0-1/Apply manual quality control
MRD552/7.4.4.1.0-1/New and updated instruments and methods	GV758/5.3.6.0-1/Maintain QC versions
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV765/5.4.1.0-1/Calculate overlap
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV770/5.4.2.0-1/Variable time offset and area overlap thresholds
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV778/5.4.3.0-1/Determine fractional area of precipitation
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV783/5.4.4.0-1/Data transformation and interpolation
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV789/5.4.5.0-1/Reflectivity transformation
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV794/5.4.6.0-1/Variable parameters for common space/ground grid
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV800/5.4.7.0-1/Gridded Radar Data Storage
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV810/5.4.8.0-1/Grid Metadata
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV822/5.4.9.0-1/Alignment

Parent Requirement	Requirement
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV827/5.4.10.0-1/Averaging
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV832/5.4.11.0-1/Extract vertical profiles
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV837/5.4.12.0-1/Exclude selected observations
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV846/5.4.13.0-1/Reflectivity Comparison Products
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV854/5.4.14.0-1/Automated QC in Comparison Products
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV860/5.4.15.0-1/Manual Override QC flags
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV866/5.4.16.0-1/Reflectivity Comparison Product Storage
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV872/5.5.1.0-1/Default parameters for coincident data
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV877/5.5.2.0-1/User-defined parameters for coincident data
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV882/5.5.3.0-1/Default parameters for common space/ground grid
MRD523/7.4.1.1.0-1/Direct assessment of satellite precipitation estimates	GV887/5.5.4.0-1/Default and user parameters for common space/ground grid
MRD552/7.4.4.1.0-1/New and updated instruments and methods	GV892/5.5.5.0-1/Manual Quality Control
MRD534/7.4.2.3.0-1/Archive MRD536/7.4.2.4.0-1/Archive search and order MRD538/7.4.2.5.0-1/Distribution	GV897/5.5.6.0-1/Routine Process Initiation
MRD534/7.4.2.3.0-1/Archive MRD536/7.4.2.4.0-1/Archive search and order MRD538/7.4.2.5.0-1/Distribution	GV902/5.5.7.0-1/Non-Routine Process Initiation
MRD534/7.4.2.3.0-1/Archive MRD536/7.4.2.4.0-1/Archive search and order MRD538/7.4.2.5.0-1/Distribution	GV907/5.5.8.0-1/User Access to Standard Validation Network Data Products
MRD556/7.4.4.3.0-1/Product distribution timeliness	GV912/5.6.1.0-1/Availability of Default Validation Network Data Products
MRD547/7.4.3.3.0-1/Nominal operations	GV917/5.6.2.0-1/User Requests for Non-Routine Data and Data Processing